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NATIONAL POLITICAL ADAPTATION IN A  
WORLD ENVIRONMENT: TOWARD A SYSTEMS  
THEORY OF DYNAMIC POLITICAL PROCESSES

Stuart J. Thorson

Ohio State University

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A SYSTEMS THEORY OF DYNAMIC POLITICAL PROCESSES

Stuart J. Thorson  
Project for Theoretical Politics  
Department of Political Science  
The Ohio State University

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<p>Foreign policy behavior is viewed as being generated by adaptive national systems, and a language appropriate to this focus is introduced. The concepts surrounding Simon's notion of an "artificial" system provide one such vocabulary. Artificial systems may be thought of as a subset of general systems and are characterized by such concepts as "goals", "inner environments", "outer environments", and interfaces." An adaptive national system is then defined as a government (I.E.) attempting to achieve goals (maintain state variables within specified limits) in an O.E. consisting of (at one level of disaggregation) the domestic environment and the international system. Several additional components of adaptive systems are mentioned and some of their implications for national systems are discussed. The definition of an adaptive system is employed to prove the impossibility of a universal adaptor and this result is used to suggest that O.E.'s be classified as to their complexity with respect to a given I.E. (national system). An illustrative proposition is derived utilizing this approach.</p>			

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### Section I: Introduction

For quite some time now, biologists have used the concept of an "adaptive" system in explaining both macro and micro level biological changes. Very loosely, (and we will be more precise further on) an adaptive system is one which manages to change either itself or its environment in such a way as to "get along." Thus, for example, we are told that dinosaurs became extinct because they failed to adapt to their environment, whereas man is unique in his ability to adapt to a wide range of environments. More abstractly, biologists distinguish between organisms which adapt to a very specific environmental niche and those which achieve a more general level of adaptation. The niche adapted organism is very unlikely to survive if his environment is changed in the least bit, while the more generally adapted organism is able to tolerate fairly wide environmental changes.

Many social scientists have thought it might prove helpful to view social phenomena from the perspective of adaptive behavior. Recently several students of foreign policy have suggested that the biologist's conception of an adaptive system could be useful in analyzing foreign policy behaviors. That is, the hope seems to be in that there is some theory of adaptive biological systems,  $T_1$ , which has a model,  $M_1$ , which is isomorphic to a model,  $M_2$ , for a theory of national foreign behavior,  $T_2$ . If  $M_1$  and  $M_2$  are isomorphic, then by the law of deduction (Tarski, 1965:125) the existing of propositions of  $T_1$  can be translated into propositions of  $T_2$ , the theory of foreign policy behavior. As an almost

trivial example, the sentence of  $T_1$  (the biological theory) which read "A niche adapted organism whose environment is changed will fail to survive" might become in  $T_2$  (the foreign policy theory) "A national system which has achieved a high degree of accurate foreign policy response of election for only a very specific international environment, will fail to survive in a changed international environment." As evidence for the proposition in  $T_1$ , the biologist might point to the rapidly disappearing Ridley turtle (whose nesting beaches are being altered) while as evidence for the proposition in  $T_2$ , the political scientist might look at the Greek city-states. This hope comes through fairly clearly in the work of several political scientists. For example, Rosenau (1967) sees the outstanding characteristic of adaptation theory as being its focus on the interaction between system and environment. "The subject matter of the foreign policy analyst is distinctive because its prime focus is the association between variations in the national actor and variations in its environment." Since 1967 Rosenau has done considerable work to develop his adaptation paradigm. McGowan (1970) has taken some of these notions and attempted to formalize them in a mathematical theory from which some of the consequences of adaptation theory can be examined empirically.

Perhaps the best way to explicate the Rosenau-McGowan approach is to quote at some length from McGowan (1970):

In his most recent elaboration of the adaptation paradigm Rosenau argues as follows: First: 'considerable insight' can be gained from viewing national societies, like a cell or an organism, 'as entities that must adapt to their environ-

ments to survive and prosper. That is, if an entity is to maintain the boundaries that separate it from other entities, it must act toward the other entities in such a way to keep its essential structures intact (Rosenau, 1970, p. 2).'  
Second, for national societies, 'adaptation means that fluctuations in the basic interaction patterns that sustain its social, economic, and political life must be kept within limits minimally acceptable to its members (Rosenau, 1970, p. 2).'  
Third, since there can be considerable disagreement over what are acceptable limits of variation in the performance of a society's economy or polity, the politics of national adaptation is infused with 'an intensity and drama unknown to other entities' and processes (Rosenau, 1970, p. 2).  
Fourth, the performance of essential societal structures is conditioned by external change, internal societal change, and the society's response to these two stimuli (Rosenau, 1970, p. 2). And  
fifth, given that any society's external environment is a basic source of variation in its essential structures, 'the need for foreign policy arises...out of the fact that the essential structures cannot be kept within acceptable limits unless some kind of behavior is undertaken toward the environment (Rosenau, 1970, p. 3).

As Rosenau has pointed out, there is interest in the interactions of a national political actor and its environment; that is, with the nation and its international environment. In terms of the familiar black box diagram of Figure 1, it would look like this:

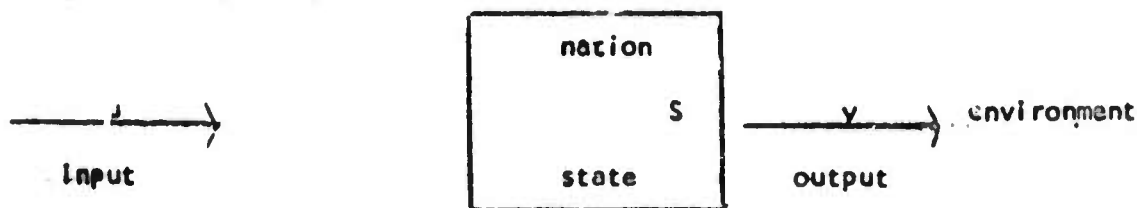


Figure 1

to have a system, however, more information must be provided than is contained in Figure 1. There must be a specification of the elements which comprise the system. In the case of a national political system, this

this is clearly no easy task and is one to which many social scientists have devoted much of their attention. Both Rosenau and McGowan recognize this problem and attempt to answer it by positing essential societal structures. Rosenau (1970) suggests four such structures:

- (1) "...the patterns whereby the life and property of societies are preserved and protected..."
- (2) "...the patterns whereby...their policy decisions (are) made and implemented..."
- (3) "...the patterns whereby...their goals and services (are) acquired and distributed..."
- (4) "...the patterns whereby...their members' cooperation (is) achieved and maintained..."

McGowan (1970) identifies five essential structures:

- (1) The boundary of the society
- (2) The society's economic system
- (3) The polity of the society
- (4) The culture of the society
- (5) The integrative system of the society

Both writers argue that any foreign policy that fails to keep these structures within acceptable limits is maladaptive. Unfortunately, neither of the two sets of essential structures is defined in such a way that makes their measurement clear. Indeed, in McGowan's case the essential structures are analytic properties of any existing national system. Thus, as variables they are either present or not present, and if any are not present, the system by definition no longer "exists." A



foreign policy which results in any of the essential structures not being present is termed maladaptive. This of course is equivalent to saying that any foreign policy which results in the destruction of nation-state is maladaptive.

There is nothing wrong with this from the vantage of general adaptation theory; however, from the standpoint of political theory McGowan's notion of acceptable limits is far too broad. For example, how should United States' involvement in Indochina be distinguished from her help in rebuilding Europe after World War II? The impacts of these two policies on the U.S. political system were very different; yet, in McGowan's sense, both are adaptive because neither resulted in the downfall of the United States. It would seem that any conception of the elements of the system ought be capable of reflecting these different impacts.

Rosenau is not so specific as McGowan on what ranges his essential structures can tolerate. He does suggest that the overall adaptation of a society can be measured by its least well adapted structure as well as how some of those structures might be measured. Rosenau argues that the structures can take on values over a fairly wide range. An example is the political structure. Here Rosenau focuses upon how much control a national system has over its own policies. As this control decreases, says Rosenau, so do the boundaries between the national and international systems begin to merge. Policies which result in decreasing this control are less adaptive than those which do not.

The problem with this sort of notion is that without carefully stating the "acceptable limits," it is impossible to label the results of a given policy "adaptive." For example, was the Egyptian reliance upon Soviet military assistance adaptive for Egypt or not?

Apart from the empirical problem of measurement and the conceptual problem of specifying limits, a further conceptual problem has arisen. In the preceding discussion "adaptive" has been used in two ways. First, mention was made of an adaptive political system. Second, certain foreign policy behaviors were said to be adaptive or maladaptive. Although at first glance these uses may appear the same, they are not. An adaptive system may at times behave maladaptively. This distinction will become more clear as some of the concepts of adaptation theory are defined more rigorously; for the present an example will have to suffice.

Some psychologists view learning as an adaptive process. That is, people learn in order to reduce certain basic drives (Hull, 1943). Learning, however, does not generally take place all at once; errors are made along the way. Some of these errors may, in fact, increase the drives rather than reduce them. In fact, no matter what limits are put on drive levels, there can always exist an error which might increase drives beyond these limits. That is, even though the learning system is conceptualized as being adaptive, it may still behave maladaptively.

The distinction just illustrated unfortunately does not seem to be consistently made by McGowan. Yet it is of importance to how the structures generating foreign policy are conceptualized. For it is

required that the foreign policies of a nation always be adaptive if the nation is to continue to exist (as McGowan seems to), something very much different is being said than simply to say foreign policy behaviors result from adaptive systems.

Already it seems the limits of the common sense vocabulary associated with adaptation theory have been reached. In order to go further the vocabulary must be developed more rigorously.

Taking the adaptation view seriously requires going beyond a simple common sense intuitive understanding of what is meant by the terms involved. A useful way of accomplishing this is to first introduce some basic systems concepts and then move to an explication of Simon's (1969) notion of an "artificial" system. As will be seen, the artificial system's framework fits in very nicely with Rosenau's emphasis upon the relation between the national actor and its environment.

## Section II: Basic Systems Concepts

A government can be viewed as a system attempting to achieve goals in two linked environments--the government's national system and the international system. This view of government as a goal seeker immediately suggests some sort of cybernetic approach to the study of foreign policy. Great care, however, must be exercised in how cybernetics is applied to avoid concentrating upon a "conventional" sort of equilibrium ("equilibrium" will be defined more rigorously further on) and ignoring the dynamic characteristics of national adaptation.

The reason the adoption of a cybernetics approach so often leads to conventional equilibrium type analysis is that much of the work in cybernetics has dealt with what are known variously as negative feedback or deviation counteracting systems. The essential attribute of these systems is that, when disturbed, they behave in such a way as to minimize the effect of the disturbance. An example of a negative feedback system is the position that if you increase the income of lower class persons, they will only have more children and, as a result, their overall economic position will not be changed. The following directed signed graph illustrates this belief structure:

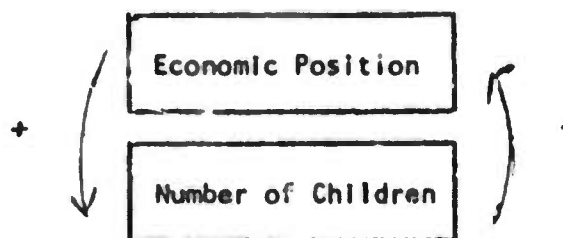


Figure 2

The positive arrow linking economic position with number of children indicates that an increase in a family's economic position will result in increasing the number of their children. The negative arrow designates that an increase in the number of children will decrease the overall economic position of the family. The arrow leading back to "economic position" has a minus sign, hence the name negative feedback system. Systems such as that in Figure 2 will generally tend toward an equilibrium state. The equilibrium values will depend upon the initial values and the size of the disturbance.

A graph such as Figure 2 may be termed a non-numerical structure. It is non-numerical in that the correspondence between the empirical referents (economic position and number of children) and the objects in the structure (the directed sign graph) preserve order relations but not magnitudes. Nothing is said about how many more children should accompany an increase of  $x$  dollars in income. It does, however, tell whether increasing income augments or inhibits the number of children in the family.

Even a casual glance at the cybernetics literature will reveal that much of the work is directed toward the analysis and design of highly sophisticated negative feedback mechanisms. In cybernetics, feedback is often used to indicate the discrepancy between the intended results and actual results of a given behavior. Generally the desire is to minimize the difference between intent and action and, as a result, an emphasis is placed upon the design of negative feedback systems.

Many aspects of social phenomenon, such as growth and patterned adaptive change, however, may often best be viewed as positive feedback mechanisms. The discussion by Coombs, et al. (1970) of the relation between the quality of faculty in an academic institution and the quality of graduate students in that institution is illustrative of this point. High quality faculty attracts high quality graduate students who in turn attract more high quality faculty. Or:

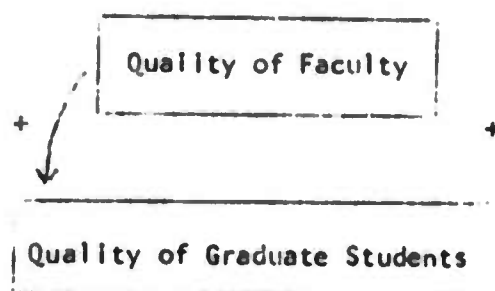


Figure 3

Figure 3 provides an example of a positive feedback structure. As can be seen, positive feedback loops augment initial disturbances.

Since the differences between positive and negative feedback systems are of some importance, it will be worthwhile to develop a numerical theory of the system shown in figure 2. For economic position ( $E$ ) and number of children ( $C$ ), the following difference equations can be written with the subscript referring to the time increment involved:

$$\begin{aligned}
 (1) \quad C_t &= \begin{cases} C_{t-1} & \text{if and only if } E_{t-1} < E_{t-2} \\ C_{t-1} + (E_{t-1} - E_{t-2}) & \text{if and only if } E_{t-1} > E_{t-2} \end{cases} \\
 (2) \quad E_t &= E_{t-1} - (C_{t-1} - C_{t-2})
 \end{aligned}$$

Here equations (1) and (2) tell that increasing a family's economic position one unit at time  $t$  will result in increasing the number of their children by one at time  $t + 1$ . Table 1 shows the results for four time periods of a family which begins with no children and whose economic position goes from 1 at time 1 to  $t$  at time  $t$ .

Table 1

$t$	$E$	$C$
1	1	0
2	2	0
3	2	1
4	1	1
5	1	1

By time 4 the system has reached an equilibrium position of  $E = 1$  and  $C = 1$ . Suppose now at time 6 a policy is instituted giving the family an increase in economic position to 3 ( $E = 3$ ). Table 2 gives the results:

Table 2

$t$	$E$	$C$
6	3	1
7	3	3
8	1	3
9	1	5

The purpose of the example is not, of course, to claim that increasing a family's economic position by two units in one time period will result in their having twins the next period. Rather, the example was intended to demonstrate the over-time behavior exhibited by negative feedback systems and to show that attempts to look at political systems as negative feedback systems will often lead to viewing them in terms of their equilibrium positions.



The claim was made earlier that a government could be viewed as a component of an artificial system attempting to achieve goals in two linked environments. In order to explicate this, it will be necessary to discuss in some detail concepts such as system, goals, goal achievement, environments, and the ways in which environments can be linked. Once these concepts are well understood, a framework can be built from which to view political adaptation and change. At first, the discussion of empirically "empty" concepts may seem a rather sterile exercise; however, unless the basic structural and manipulative concepts are well in mind, the empirical interpretation which follows will be difficult, if not impossible, to evaluate.

A system may be defined as a set of objects together with the relations defined upon them. Thus a system is identical to a mathematical structure. The object is the basic building block of the system. Figure 2 describes a two object, two relation system. The objects are economic position (E) and number of children (C) and the relations are augmentation from E to C and inhibition from C to E. If the augmentation relation is denoted as  $R_+$  and the inhibition relations as  $R_-$ , the system (mathematical structure) of Figure 2 looks as follows:

$$S: \langle E, C; ER_+C, CR_-E \rangle$$

Note the objects of S are listed first and then the relations obtaining between them.

Consider now a system described by equations (1) and (2):

$$S^*: \langle E_t, C_t; ER_+^*C, CR_-^*E \rangle$$



The state of the system at a point in time is simply the value of each object in the system at that point. Thus from Table 2, the state of  $S^*$  at time 6 is ( $E = 3$ ,  $C = 1$ ).

Most phenomena are not completely closed off from other phenomena; that is, there are interactions among phenomena. When a system is abstracted from such a phenomenon, it is generally called an open system, reflecting the fact that the system receives some sorts of inputs from the outside. Most all systems not only receive inputs, but they also have some way of sending outputs to the outside. This type of open system is the one depicted in the "black box" diagram of Figure 1. Here system  $S$  receives input  $u$  and sends output  $y$ . That which is external to the system is often called the system's environment.

A question of considerable interest to systems theorists is whether the system has an equilibrium point and, if it has, if the equilibrium is stable. A system state is said to be an equilibrium state if it is a state from which the system does not move unless it receives some external shock from its environment. Environmental shock here refers to some change in the environment which does not result from a change in the system. If a shock moves the system away from its equilibrium state and the system eventually moves back to equilibrium, then the equilibrium is said to be a stable one. A distinction is often made between two sorts of stability. The first is called asymptotic stability. Here if the shock does not move the system outside of some region about the equilibrium point, the system will return to equilibrium.

This region is referred to as the region of asymptotic stability. On the other hand, it may be that no matter where the system is moved, it will return to the equilibrium state. This property is called global stability. A system which is globally stable has its entire state space as a region of asymptotic stability.

Oftentimes because of measurement problems or a lack of conceptual precision it is impossible to determine whether or not a system is "really" in the same state. To help avoid these problems the definition of an equilibrium state can be relaxed by allowing each element a slight bit of variation resulting in a zone of equilibrium. Each state in this zone is not exactly the same as every other but they are, in a strictly defined sense, very close. As long as the system is in a state contained in this zone, it can be said to be in an equilibrium state.

An example might make this more clear. Imagine a system obstructed from a human being composed of his body temperature, pulse, and respiration rate. The system can then be thought of as a triple  $\langle T, P, R \rangle$ . A person whose temperature is 98.6, pulse is 100 beats per minute, and respiration rate is 15 breaths per minute can be represented by  $\langle 98.6, 100, 15 \rangle$ . After making many observations it is noted that all three of these variables normally fluctuate a bit but tend to remain within certain limits. Suppose these limits are as follows:

<u>Variables</u>	<u>Normal Range</u>
T	97.0 - 99.4
P	85 - 115
R	12 - 18

By appropriately defining a zone of equilibrium, the system  $\langle T, P, R \rangle$  can be said to be at equilibrium as long as each element is somewhere in its normal range.

After watching human beings a while longer, it might be decided to add a few more elements to the system: say blood pressure (B), output of the sweat glands (S), and behavioral activation level (A). If the states of this new system  $\langle T, P, R, S, B, A \rangle$  were measured and recorded at closely spaced intervals and over a long period of time, it might be noted that whenever one of the variables moved outside of its normal limits, others would also move and the system would eventually return to equilibrium. Thus, for example, if the body temperature were to rise, the sweat glands might increase their output, cool off the body and the system would move back to its equilibrium region. In general, the system remains at equilibrium and the equilibrium is a stable one.

The sequence of outputs generated by a system is called its behavior. A goal or objective for a numerical system is a specification of the set of desired system states. In the example, a goal might be any system state where  $T$  is between 97.0 and 99.4,  $85 \leq P \leq 115$ , and  $12 \leq R \leq 18$ . The terms goal and objective will be used interchangeably.

It is important to recall that from the way system has been defined-- a set of objects together with the relations defined upon them--it would be meaningless to talk about structureless systems. What is viewed as structure and what is not is, of course, dependent upon how the system of study is conceptualized. For example, Toda and Shuford (1965) ask: "When one cuts his finger with a knife, quite a number of tissue cells are ruined. Does this mean a change in the structure of this person?" The answer to their question is yes and no. If the objects of the person are said to be cells, then clearly there is a structure change. However, if the objects are more macroscopic body parts such as fingers, then cutting the finger simply changes the finger's state but does not change the structure of the system. A system is a mathematical structure and its elements and relations must be specified precisely if it is to be discussed meaningfully.

As will be shown, clear system specification is of crucial importance to anyone doing empirical comparative research. First, however, one more concept--that of a parameter--needs to be introduced at this point. Given a system, any element not included in it is a parameter. Some parameters may have no effect upon a system, others may have an effect only under certain conditions, and still others may have a very direct effect at all times. A more precise understanding of what is meant by a parameter should come from the example about to be presented.

Brunner (1970) provides a very nice discussion of some of the problems involved in doing comparative research when the systems involved are not well specified.

The theory used in this example will be one based upon Samuelson (1939). The objects in the system being theorized about are:

$S_t$  = overall satisfaction level of the people in a given nation at time  $t$

$P_t$  = performance of the private sector of the nation at time  $t$

$G_t$  = performance of the government of the nation at time  $t$

These objects (variables) can be related as follows:

$$(3) \quad P_t = \alpha S_{t-1}$$

$$(4) \quad G_t = B(P_t - P_{t-1})$$

$$(5) \quad S_t = P_t + G_t \quad \text{where } \alpha \text{ and } B \geq 0$$

(3) states that private sector performance will be proportional to the preceding period's level of overall satisfaction. Equation (4) tells that government performance will be proportional to the change in private sector performance from this period to the preceding period. Finally, (5) is a simple accounting equation defining overall satisfaction to be the sum of government performance and private sector performance. Throughout this analysis it will be assumed that  $S$ ,  $P$ , and  $G$  are measured in comparable units.

Figure 4 illustrates the structure of this set of equations. The single arrows signify no time advance and the double arrows indicate a time advance of one unit.

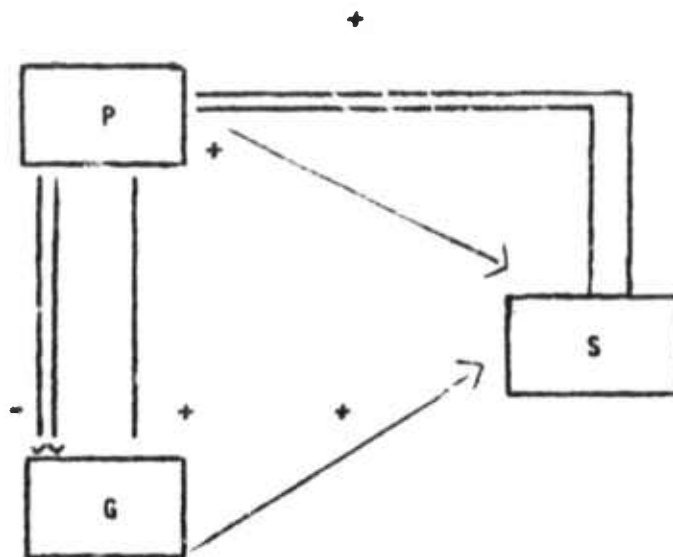


Figure 4

The state variables of the structure are  $G$ ,  $P$ , and  $S$  and the relations among these state variables are depicted in Figure 4. The parameters which directly affect the structure of Figure 3 are  $\alpha$ ,  $B$ , and  $t$ . They are not included in the structural diagram of the equations.

Imagine four national systems ( $N_1, N_2, N_3, N_4$ ) each of which is described by equations (3) - (5) but differ in their values of the parameters  $\alpha$  and  $B$ . In  $N_1$ ,  $\alpha = .8$ ; and  $B = 1.5$ ; in  $N_2$ ,  $\alpha = .8$  and  $B = 3.0$ ; in  $N_3$ ,  $\alpha = .5$  and  $B = 0$ ; and in  $N_4$ ,  $\alpha = .5$  and  $B = 1.0$ . The initial value ( $t = 1$ ) of  $P$  and  $G$  is 0 in all four systems and the initial value ( $t = 1$ ) of  $S$  is 1 in all the systems. Equations 3, 4, and 5 can be programmed on a computer and by substituting the appropriate values for  $\alpha$  and  $B$ , the states of each system for different values of  $t$  can be generated. Figure 5a shows the results of these runs.

As can be seen, each system exhibits very different behavior. The elements in  $N_3$  and  $N_4$  all go to an equilibrium state of  $(0, 0, 0)$ .

though those in  $N_3$  approach it directly while those in  $N_4$  oscillate to it. The elements of  $N_1$  swing through increasing oscillations and those in  $N$  increase at a very rapid rate. These extremely diverse behaviors may be thought of as resulting from the same system. Would a political scientist analyzing the data in Figure 5 with conventional linear techniques recognize that each nation's behavior was generated by the same structure?

Brunner (1970) demonstrates very convincingly that the data analysis strategies presently employed by most political scientists (such as conventional regression analysis) will usually not reveal the underlying structure of the system. This will generally be the case whether the systems are analyzed cross-nationally at a point in time or individually as a time series. (See Brunner, 1970, pp. 6-7, for a more complete treatment of these data analysis problems.)

As considered thus far, this example illustrates several important problems facing political analysts. First, there is the very broad data analysis problem. To what extent can data--even time series data--be used to identify the basic structure of a model for a theory of national behavior? Since most analysis strategies cannot be used to distinguish between structure and parameters, it is the responsibility of the analyst to impose a basic structure on his observations prior to doing statistical manipulations. As Cain and Watts (1970, p. 229) point out, 'Without a theoretical framework to provide order and a rationale for the large numbers of variables, we have no way of inter-



$N_1$				$N_2$				20.
$\alpha = 0.800$ $\beta = 1.500$				$\alpha = 0.800$ $\beta = 3.000$				
T	S(T)	P(T)	G(T)	T	S(T)	P(T)	G(T)	
1	1.000	0.000	0.000	1	1.000	0.000	0.000	
2	2.000	0.800	1.200	2	3.200	0.800	2.400	
3	2.800	1.600	1.200	3	7.840	2.560	5.280	
4	3.200	2.240	0.960	4	17.408	6.272	11.136	
5	3.040	2.560	0.480	5	36.890	13.926	22.963	
6	2.240	2.432	-0.192	6	76.267	29.512	46.756	
7	0.832	1.792	-0.960	7	155.521	61.014	94.507	
8	-1.024	0.666	-1.600	8	314.625	124.417	190.208	
9	-3.046	-0.819	-2.727	9	633.549	251.700	381.849	
10	-4.864	-2.437	-2.427					
11	-6.072	-3.891	-2.181					
12	-6.308	-4.858	-1.450					
13	-5.329	-5.046	-0.283					
14	-3.088	-4.263	1.175					
15	0.218	-2.471	2.689					
16	4.142	0.174	3.968					
17	8.022	3.314	4.709					
18	11.074	6.418	4.656					
19	12.755	8.859	3.662					
20	11.755	10.017	1.737					

$N_3$				$N_4$			
$\alpha = 0.500$ $\beta = 0.000$				$\alpha = 0.500$ $\beta = 1.000$			
T	S(T)	P(T)	G(T)	T	S(T)	P(T)	G(T)
1	1.000	0.000	0.000	1	1.000	0.000	0.000
2	0.500	0.500	0.000	2	1.000	0.500	0.500
3	0.250	0.250	0.000	3	0.500	0.500	0.000
4	0.125	0.125	0.000	4	0.000	0.250	-0.250
5	0.062	0.062	0.000	5	-0.250	0.000	-0.250
6	0.031	0.031	0.000	6	-0.250	-0.125	-0.125
7	0.016	0.016	0.000	7	-0.125	-0.125	0.000
8	0.008	0.008	0.000	8	-0.000	-0.062	0.062
9	0.004	0.004	0.000	9	0.062	0.000	0.062
10	0.002	0.002	0.000	10	0.062	0.031	0.031
11	0.001	0.001	0.000	11	0.031	0.031	0.000
12	0.000	0.000	0.000	12	0.000	0.016	-0.016
13	0.000	0.000	0.000	13	-0.016	0.000	-0.016
				14	-0.016	-0.008	-0.008
				15	-0.008	-0.008	0.000
				16	-0.000	-0.004	0.004
				17	-0.004	0.000	0.004
				18	0.004	0.002	0.002
				19	0.002	0.002	0.000
				20	0.000	0.001	-0.001
				21	-0.001	0.000	-0.001
				22	-0.001	0.000	0.000
				23	0.000	0.000	0.000
				24	0.000	0.000	0.000

Figure 5a



$N_1$   
 $\alpha = 0.800$   $\beta = 1.500$

T	S(T)	P(T)	G(T)
1	1.000	0.000	0.000
2	0.800	0.800	1.200
3	0.640	0.640	-0.240
4	0.512	0.512	-0.192
5	0.410	0.410	-0.154
6	0.328	0.328	-0.123
7	0.262	0.262	-0.098
8	0.210	0.210	-0.079
9	0.168	0.168	-0.063
10	0.134	0.134	-0.050
.	.	.	.
.	.	.	.
.	.	.	.
34	0.001	0.001	0.000
35	0.001	0.001	0.000
36	0.000	0.000	0.000
37	0.000	0.000	0.000

$N_2$   
 $\alpha = 0.800$   $\beta = 3.000$

T	S(T)	P(T)	G(T)
1	1.000	0.000	0.000
2	0.800	0.800	2.400
3	0.640	0.640	-0.480
4	0.512	0.512	-0.384
5	0.410	0.410	-0.307
6	0.328	0.328	-0.246
7	0.262	0.262	-0.197
8	0.210	0.210	-0.157
9	0.168	0.168	-0.126
10	0.134	0.134	-0.101
.	.	.	.
.	.	.	.
.	.	.	.
34	0.001	0.001	0.000
35	0.001	0.001	0.000
36	0.000	0.000	0.000
37	0.000	0.000	0.000

$N_3$   
 $\alpha = 0.500$   $\beta = 0.000$

T	S(T)	P(T)	G(T)
1	1.000	0.000	0.000
2	0.500	0.500	0.000
3	0.250	0.250	0.000
4	0.125	0.125	0.000
5	0.062	0.062	0.000
6	0.031	0.031	0.000
7	0.016	0.016	0.000
8	0.008	0.008	0.000
9	0.004	0.004	0.000
10	0.002	0.002	0.000
11	0.001	0.001	0.000
12	0.000	0.000	0.000
13	0.000	0.000	0.000
14	0.000	0.000	0.000

$N_4$   
 $\alpha = 0.500$   $\beta = 1.000$

T	S(T)	P(T)	G(T)
1	1.000	0.000	0.000
2	0.500	0.500	0.500
3	0.250	0.250	-0.250
4	0.125	0.125	-0.125
5	0.062	0.062	-0.062
6	0.031	0.031	-0.031
7	0.016	0.016	-0.016
8	0.008	0.008	-0.008
9	0.004	0.004	-0.004
10	0.002	0.002	-0.002
11	0.001	0.001	-0.001
12	0.000	0.000	0.000
13	0.000	0.000	0.000
14	0.000	0.000	0.000

Figure 5b

preting the statistical results." Regression analysis is properly used to estimate population parameters only when the structure of the model elements are already specified. This specification of structure must precede the application of parameter estimation techniques.

A second problem is the very subtle distinction between structural differences and state differences. The various behaviors of the four imaginary nations all resulted from the same basic structure. In positing systems it is this structure which must be isolated, and, in doing so, care must be exercised not to assume fallaciously that because two nations pass through very different states (e.g., exhibit very different behaviors) they must be modeled by different structures. It may, of course, be that different structures are appropriate, but this will not necessarily be the case.

With the structure of Figure 4 and the parameter values specified in Figure 5, it has been shown that the same structure can result in very different over-time behavior. Suppose now the theory is changed by making equation (5) read:

$$(5') S_t = P_t$$

Equation (5') asserts that overall satisfaction will simply be equal to private sector performance and that the government performance has no effect upon satisfaction. The result of this structural change is to push the four elements of  $N_1$ ,  $N_2$ ,  $N_3$ , and  $N_4$  to an equilibrium position of  $\langle 0, 0, 0 \rangle$ . The over-time behaviors of each of these systems can be seen in Figure 5b. Though all four systems end up in

the same state, their behavior paths in getting there are again different. In this case, the theory change did not affect the equilibrium positions of  $N_3$ , and  $N_4$ , even though it did affect the sequence of states  $N_4$  passed through in getting to equilibrium. Changing the theory with equation (5') demonstrates how inadequate a characterization of system behavior is the conventional concept of equilibrium. Simply knowing that two systems have the same equilibrium point gives very little information about whether they are isomorphic.  $N_3$ , it will be recalled, behaved exactly the same before and after the structure change. The systems in Figure 5a were isomorphic yet two went to equilibrium and two did not.

Further, interest will often be centered upon what states a system passes through in getting to equilibrium. A given policy (sequence of outputs of the I.E.), for example, which would move the overall system to a desired equilibrium point might be rejected if it was known that getting to that point entailed the system's going through some highly undesirable states. Specifically, while equations (5) and (5') will be behaviorally indistinguishable when  $G$  (or  $\bar{p}$ ) is equal to zero, very different policies will be recommended if the level of satisfaction is a function of the government's performance (although observed government performance is equal to zero) than if satisfaction is unrelated to government performance.

### Section III: Artificial Systems and Adaptive Systems

Having defined a system, it is possible to move to a discussion of a specific sub-class of systems--artificial systems. While the distinction between "artificial" and "natural" systems is not always clear, the basic idea is that artificial systems are directed to human goals whereas natural ones may not be. Simon (1969, pp. 5, 6) suggests four criteria for separating the artificial from the natural:

- "1. Artificial things are synthesized (though not always or usually with full forethought) by man.
2. Artificial things may imitate appearances in natural things while lacking, in one or many respects, the reality of the latter.
3. Artificial things may be characterized in terms of functions, goals, adaptation.
4. Artificial things are often discussed, particularly when they are being designed, in terms of imperatives as well as descriptives."

Thus, for example, a forest would be a natural system while a farm would be an artificial system.

We can talk about artificial systems as having an inner environment (I.E.) attempting to achieve some goal(s) in an outer environment (O.E.). The hookup between the I.E. and the O.E. is called the interface. Bailey and Holt (1971) break the interface into two parts and put the I.E. and O.E. into a control theoretic structure as in the following figure:

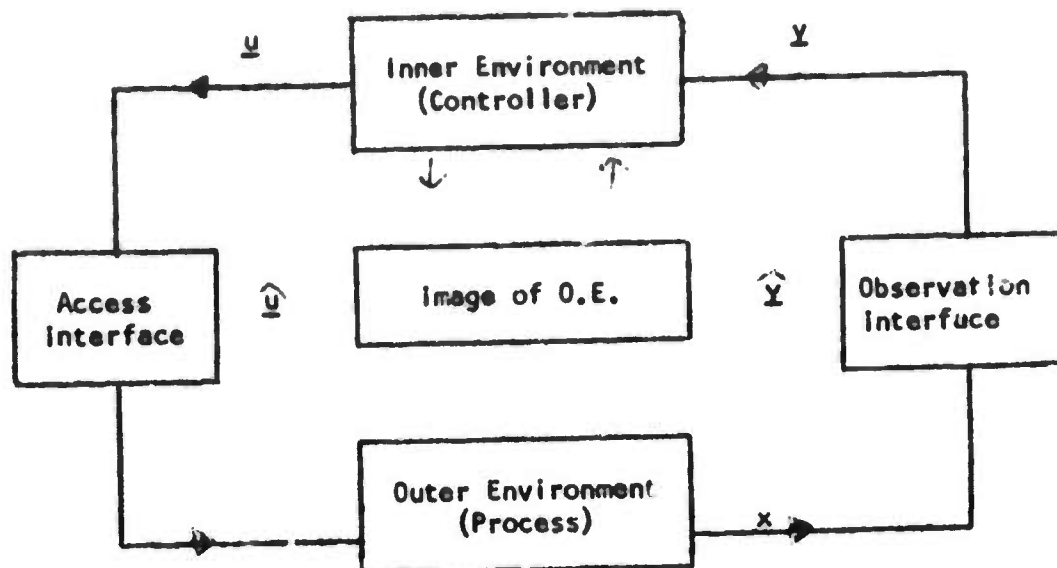


Figure 6

Figure 6 is very general, but does illustrate the additional structure common to all artificial systems.

The easiest way to describe the scope of this diagram is through a very simple example. Let the inner environment (I.E.) be a country's government and the outer environment (O.E.) be the economic system of that country. Suppose further that the government's goal is to remain in power and that it "believes" it can do so only by keeping the economic system in a certain specified set of acceptable states. The state of the O.E. is represented by the vector  $\underline{x}$  and might include such things as each citizen's income, all sales transactions, and other such elements.

The government must have some way of observing  $\underline{x}$  so that it can know whether the economy is in an acceptable state and yet it could not observe each and every sales transaction, etc. directly nor, even if it

could get it, would it be able to process the information. The problem of observing the O.E. is represented in Figure 6 by the observation interface. The observation interface may be thought of as the I.E.'s sensing device in the O.E. In the case of our example, the government might set up various agencies to collect economic data. Since, in this example,  $\underline{x}$  would contain way too much information, the I.E. incorporates into the observation interface an indicator system. Thus instead of having  $\underline{x}$  as an input, the I.E. receives  $\underline{y}$ . The vector  $\underline{y}$  might include such indicators as GNP and unemployment rates. In some cases  $\underline{y}$  and  $\underline{x}$  will be equivalent. Most often, however, this will not be the case and it is important that the notation reflect this possible distinction.

Upon receiving  $\underline{y}$ , the I.E. must evaluate it to determine what sort of policy is indicated. This evaluation may be thought of as taking place in the I.E.'s image of the O.E. In our example the image might consist of a Walrasian equilibrium model of the economy. Generally, this image will, at least in part, contain the elements of  $\underline{y}$ . In this way  $\underline{y}$  can be used to set the "state" of the image and various policy alternatives ( $\underline{u}$ ) can be put into the image to assess their differential impacts ( $\underline{v}$ ). Generally the  $\underline{u}$  producing the most desired  $\underline{y}$  value will be chosen as the value of  $\underline{u}$  to send into the O.E. The elements of the  $\underline{u}$  vector, to have any impact, must have some way of getting into the O.E.; that is, the I.E. must have some access interface which is capable of implementing  $\underline{u}$  in the O.E. Fiscal and monetary policy serve as accesses for the government in the example we

have been discussing. The preceding rather crude illustration suggests the high degree of inter-relation between the various elements--goals, i.e., O.E., image, and interfaces--of artificial systems.

With these concepts it is possible to explicate what is meant by an adaptive system. Before proceeding to the definition, however, it should be made clear that there is no "generally accepted" definition of an adaptive system. Indeed there are many competing definitions which are inconsistent with each other. This fact does not imply that most or even some of these definitions are "wrong." It simply means that no definition has been put forward which was so persuasive as to induce the abandonment of all other competing definitions.

An adaptive system can be defined as any system which generates outputs in such a way as to seek to maintain state variables within certain limits. Adaptive systems are goal-seeking systems. The goal is expressed in terms of desired values of state variables. Such systems may or may not have equilibrium states. In investigating adaptive systems, the analyst is concerned with the goals of the system; how, if at all, goals can be modified; how outputs are judged as successes or failures; the mechanism through which information about the environment and past system states is transformed into outputs; and other such questions.

Murphy (1965) has identified several properties of all adaptive systems whether they be social, biological, physical, or engineering:

- (1) At any point in time the system can move off in any one of a number of directions.



- (2) Any of these moves will be followed by a change in the system and perhaps in the environment. These changes become a part of the historical record of the system.
- (3) Every adaptive system must have some sort of decision-making function. On the basis of the historical record and an evaluation of the effect of each action on the present and future states of the system, the decision-making function chooses one of the alternative actions.
- (4) Following the taking of an action, the system may or may not achieve the anticipated results. Uncertainties in the environment or the effect of the action may cause the system to move in a direction which was unintended.
- (5) If the result was unfortunate, there is no recourse. The only corrective measure is to reestablish the above sequence of events all over again.

Clearly, then a simple "black box" system is not enough to illustrate an adaptive system. Several components must be in the black box before it can be labeled adaptive. First, the system must have contained some sort of internal clock so that it can sort out and act upon inputs coming at various times. This clock may not be the familiar sidereal one measuring time continuously and in constant intervals. The 'time' measured by the clock is an important problem. For if the dynamic aspects of adaptive (or maladaptive) change are to be studied, the analyst must have in mind a well-understood view of time.

The analysis of time presented here will follow very closely that of T. Windeknecht (1971). At first this may appear needlessly abstract. Hopefully, however, the abstraction will prove of help in examining political adaptation and change.



A set  $T$  together with a function  $+$  which maps the cartesian product  $T \times T$  into  $T$   $[T \times T \rightarrow T]$  which satisfies the associative axiom:

$$t + (t' + t'') = (t + t') + t''$$

for all  $t, t', t''$  belonging to  $T$  is known as a semigroup. A semigroup with an element  $0$  belonging to  $T$  such that:

$$t + 0 = 0 + t$$

for all  $t$  belonging to  $T$  is a monoid.

Given a monoid  $T$ , left division over  $T$  is the relation on  $T$  such that:

$$t < t' : (t'') : t'' \neq 0 \wedge t' = t + t'' \quad (t'' \in T)$$

where:

$$\langle \Rightarrow \rangle \equiv \text{"if and only if"}$$

$$\exists (x) \equiv \text{"There exists an } x \text{ such that"}$$

$$\wedge \equiv \text{"and"}$$

$$\in \equiv \text{belongs to}$$

The left division relation asserts a simple ordering over the elements of  $T$ .

A time set is then defined as a monoid  $T$  with the following three properties:

- (I)  $(\exists t_1) (\exists t_2) : (t_1 = 0 \vee t_2 = 0) \wedge t_1 + t = t' + t_2 \quad (t_1, t_2 \in T)$
- (II)  $t_1 + t = t + t_2 \langle \Rightarrow \rangle t_1 = t_2$
- (III)  $t_1 + t = 0 \Rightarrow t_1 = 0$

where

$$\vee \equiv \text{"or"}$$

$$\Rightarrow \equiv \text{"implies"}$$

Two sets which meet the definition of a time set are the set of nonnegative real numbers (e.g., 1, 2.5, 3.4) and the set of nonnegative integers (e.g., 1, 2, 3,...). In both cases the identity element is 0 and the left division relation is that of less than ( $<$ ) on the positive numbers.

Why, it might be asked, is there a need to be so formal and abstract in talking about time; after all, does not everyone know what time is? There are several reasons for taking a formal approach. First, as may have been noticed, a time set is a system. Examples have already been given of problems which can arise when the elements and relations of a system are not carefully defined. Since time is such an important concept, care must be exercised not to fall unknowingly into traps simply by being careless in defining time. Second, work by Arbib (1966) and Bellamy and Melt (1971) suggests that control theory and automata theory are to work together in the same structure, time must be viewed as an ordered monoid rather than an ordered group. (for an example, see Winderknecht, (1971), p. 61.)

Further, looking at time abstractly enables getting outside of the idea of time necessarily being measured in seconds, minutes, hours, days, years, and other such units. The way time has been defined here, it is essentially an ordering concept in that it gives a way to "tag" different observations in a meaningful way. Albert Einstein wrote of time (quoted in Barnett (1948, p. 47, 63): "The experiences of individual appear to us arranged in a series of events; in this series

the single events which we remember appear to be ordered according to the criterion of 'earlier' and 'later'. There exists, therefore, for the individual, an I-time, or subjective time. This in itself is not measurable. I (Einstein) can, indeed, associate numbers with events, in such a way that a greater number is associated with the later event than with an earlier one. This association I can define by means of a clock by comparing the order of events furnished by the clock with the order of the given series of events. We understand by a clock something which provides a series of events which can be counted...every reference body (or coordinate system) has its own particular time; unless we are told the reference body to which the statement of time refers, there is no meaning in a statement of the time of an event." Earlier, Gunn (1929) argued that a major problem in physics was the confusion between physical time, mathematical time, and clock time. More recently, Ornstein (1969) claims that modern psychology has been held back by confusing experiential time, clock time and biological time.

A problem for the student of politics is to develop a concept of time which is, in some as yet not well-defined sense, consistent with the phenomenon he is studying. It must be emphasized that there is no a priori reason why this conception should be the everyday calendar time generally used by political scientists. Several examples may help to illustrate this point. In the United States elections for the House of Representatives are held every two years. Great Britain, on the other hand, elects its House of Commons at least every five years or

whenever it is dissolved by the Prime Minister. If the presence or absence of U.S. Congressional elections and British Parliamentary elections were plotted against calendar time, it might be concluded that in the U.S. elections are held very regularly while in Britain they are not. This conclusion would be warranted if by "regular" was meant something like "evenly spaced in calendar time." For the purpose of doing comparative research, however, this may not be a desirable sense "of" "regular" to use. Instead regular might be used in a more general manner to mean "evenly spaced in a system with reference to that system's clock."

This formal analysis of time served to suggest the minimum structure thought to be necessary to a time concept. A question which requires much additional thought is that of how to add substance to this structure in such a way as to have a time concept which seems to tie in with political phenomena. This is especially important in making inferences to the structures of the models of nations from observations on variables ordered by calendar time. An explicit conception of time must be an aspect of the theory which suggested the observations or else there will be no appropriate means of ordering these observations.

Independent of the specific conception of time which is eventually adopted, a dynamic system can be defined as one which is directly parameterized by time. The government 'satisfaction' theory discussed earlier is an example of a dynamic system. By "directly parameterized" it is roughly meant that the value of the time parameter affects directly the values of the system elements.

If, as was suggested earlier, many social processes are growth processes best modeled by positive feedback systems, then this together with a concept of time suggests that the kinds of stability notions which have been so useful in analyzing dynamic physical systems may have very limited applications in the study of the dynamics of political adaptation. The best known example of a stable dynamic physical system is a marble in a bowl. When perturbed (within certain limits) the marble will return to its position at the bottom of the bowl. However, political systems may well not be best studied in terms of this notion of "point stability." What may be required is a higher order notion of stability. A biologist, C. H. Waddington, (1957, p. 32) has suggested the concept of chreod to refer to a trajectory in a system's state space which acts as an attractor to other trajectories. The notion of chreod may be illustrated as follows.

Imagine a large area of land containing several rivers and having all the land belonging to one or another river basin. This arrangement is shown in Figure 7. The idea of a river basin entails that water falling into basin 1 will, in most cases, eventually end up in river 1 and so on for basins and rivers 2 and 3. Once the water gets into a given river bed it will flow the path of the river. The only way for water from one basin to get into the river of another is through some unusual outside force such as its being carried in a pail or diverted through a canal. For water in basin 1, river bed 1 is a chreod. River beds 2 and 3 are chreods for water in river basins 2 and 3.

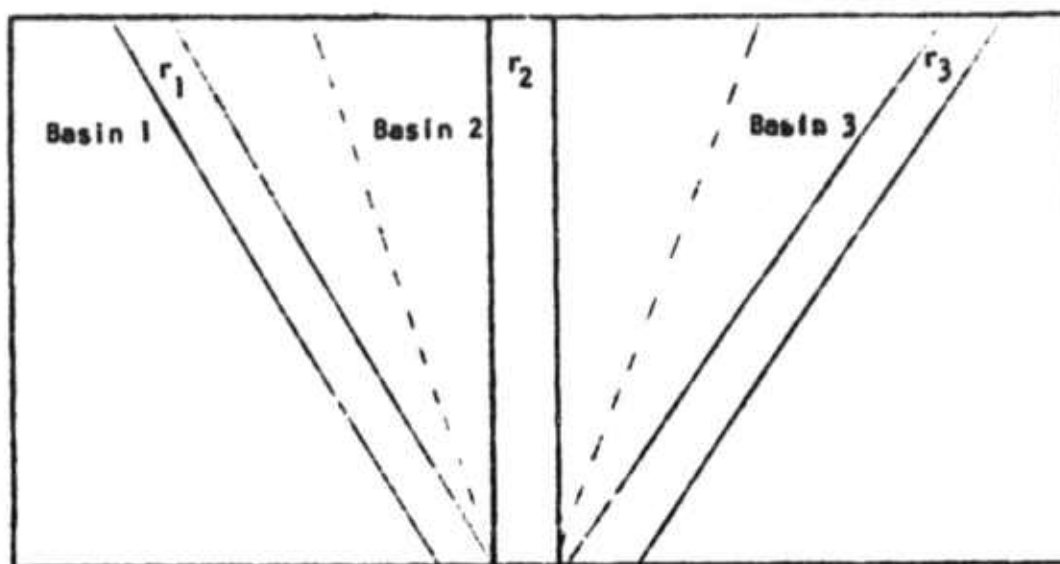


Figure 7

In a loose sense, a chreod is a higher order stability wherein it is the path about which the system is stable rather than a specific point. Chreods are essentially "developmental pathways" for the system of study. Most of the formal work which has been done in this area is by the French topologist Rene Thom. Thom (1968, 1970) sees as a fundamental problem the explanation of the stability of a temporal (i.e., dynamic) structure in terms of the organization of that structure. This problem can often be resolved by describing the process by a chreod.

Certainly Thom's problem is an important one for the political scientist. How can the stability of a dynamic political system be explained in terms of the organization of the structure of the model of that system. Note here that stability means correspondence to the chreod and not lack of violence or point stability.

Let us now return to the second of Murphy's requirements for an adaptive system; that is, the system must have some kind of memory. This is necessary if the system is to act, in part, on the basis of its historical record. Implied by this is Ashby's requirement that all adaptive systems be feedback systems. Third, the adaptive system must have a decision rule which can evaluate the past performance and the present state to choose among alternative behaviors. Fourth, it must have some sort of goal or objective. The goal may be viewed as setting and retaining state variables within certain limits.

Hopefully, the notion of an adaptive system is now clear enough to allow examining how this structure might be generalized to be relevant to the study of foreign policy.



#### Section IV: Adaptative Systems and Foreign Policy

Indeed it has already been pointed out that the notion of adaptation is not at all new in political analysis. Its emphasis upon goal-seeking systems meshes nicely with intuitive feelings about political actors. Politicians behave in a manner which is designed to help them to meet their goals. Certainly there is no obvious reason a nation's behavior cannot be looked at in an analogous fashion. Hanrieder (1967) defines foreign policy as "...the more or less coordinated strategy with which institutionally designated decision-makers seek to manipulate the international environment." Unless the argument is made that these foreign policy manipulations are made willy-nilly and without intended direction, it must be that they are aimed at reaching some goal.

Clearly if adaptation theory is to be interpreted as an empirical theory of foreign policy behavior, the problem of specifying acceptable limits on measureable state variables must be resolved. However, without doing this it is still possible to make some qualitative statements about how various sorts of adaptive systems might respond to certain kinds of environmental changes by building upon the artificial systems framework developed earlier. To do this, these constructs must be interpreted in a way helpful to the student of politics. For example, it is not very enlightening to simply relabel an I.E. as the government unless there exists an appropriate vocabulary with which to discuss governments. "Appropriate" here refers to the necessity for the



vocabulary to fit with both social science results and the artificial systems framework.

A goal or objective has already been defined to be a set of desired system states. Without getting into the empirical problems associated with trying to determine the goals of any particular nation, it is still possible to make some general statements about how goals may be viewed from the vantage of artificial systems.

In designing policies (sequences of 'u's) to achieve goals in the O.E., the responsible decision-making components of the I.E. must, in their image of the O.E., categorize the variables and parameters of the O.E. as to whether they are manipulable or non-manipulable and whether they are exogenous or endogenous:

1. Manipulable variables are those whose values are directly controllable by the given I.E. decision component.
2. Non-Manipulable variables may vary by functions of other variables in the models but not directly controllable by I.E. decision component actions.
3. Exogenous variables affect but are not directly affected by the other variables in the O.E.
4. Endogenous variables are those which may affect other variables and are effected by other variables in the system.

In conceptualizing these distinctions, the following classification table may be helpful. Endogenous-manipulable variables cannot exist since, by definition, endogenous variables can only be affected through exogenous ones.

Table 3

	Manipulable	Non-Manipulable
Exogenous	Generally the Policy Variables	?
Endogenous	None	Often Used as Performance Measures

It is important that the policy-maker be aware of which O.E. variables he is able to directly manipulate through his policy choices and which he is not. Yet this distinction is generally overlooked by behavioral scientists rushing to "explain" large percentages of variance with very few variables. In constructing theories of the O.E., decisions must be made as to which variables ought be included in the theory and which ought be excluded. These decisions, in turn, suggest devising measures of variable "significance."

If the objective of a particular theory is to parsimoniously describe the "behavior" of the O.E., then a criterion for including or excluding a given variable such as "proportion of variance explained" makes perfectly good sense (assuming, of course, there are independent

reasons to believe the underlying structure has been identified) as a way of isolating "significant" variables. However, if a goal of the theory is to enable its user to somehow change the behavior of the O.E., the import of an inclusion criterion such as "percent of variance explained" may be greatly reduced. It would be as if an egregiously overweight person were told by his doctor that a carefully done empirical study of body weight showed that height and age are only "significant" correlates of body weight. Based on this "theory," it is unlikely that anything can be done about his overweight problem (short of perhaps cutting him off at the knee or adding several feet of leg. (For a more extended treatment of this topic, see Kanter and Thorson (1972).

Not all variables are equally susceptible to manipulation by every component of the O.E. One's relation to the policy process will have an important effect on partitioning variables according to manipulability. The proverbial New York taxi driver may well understand which actions will influence the arms races, but, for people in his position, few if any variables are manipulable. Presumably, from the perspective of the President, a somewhat larger number of variables are controllable. Since which variables are "important" in a 'policy' theory depend in part on which variables are manipulable, the designer of 'policy' theory should be sensitive to the position of the theory's consumer. The theory for providing advice to the President will be "significantly" different from the theory which yields responses appropriate to taxi drivers.

A given component of the I.E. (i.e., "the government," or that portion of the government which makes foreign policy decisions) in selecting foreign policy alternatives can be viewed as facing decision problems with the following elements (adapted from Ackoff, 1962):

$C_i$  = an  $n$  element vector of manipulable variables

$U$  = a set of values for the non-manipulable values

$f(C_i; U)$  = the image of the O.E.; a set of functional relations between the elements of the O.E.

$V_i$  = the value to the decision maker of implementing alternative  $i$

$P_i$  =  $m$  element vector of performance measures affected by implementation of policy alternative  $i$

$g(P_i)$  = objective function transforming  $m$ -performance measures into (ideally) a scalar to be maximized or minimized

$X_i$  =  $j$ -element vector of policy alternatives,  $x$

With this notation, the following functions can be written:

$$V_i = g(P_i)$$

$$P_i = f(C_i; U)$$

Moreover, the decision problem facing the particular component of the I.E. can be defined. Constraints--be they political, physical, fiscal, etc.--rule out some policy alternatives as infeasible. Therefore, only the reduced set of feasible alternatives  $X^f$  need be considered. An optimal policy,  $\hat{x}$ , can then be defined as one which satisfies the following function (Mesarovic, 1970 and Richardson and Pelsoci, 1971):

$$(\forall x)_{x \in X^f} \quad g(P_{\hat{x}}) \geq g(P_x)$$

where  $R$  is generally a relation such as  $\geq$  or  $\leq$ . As an illustration, suppose the goal is to minimize  $g(P_i)$ . The I.E. component would then want to select a policy alternative  $\hat{x}_i^f$  from  $x^f$  such that  $g(P_{\hat{x}_i^f})$  is less than or equal to  $g(P)$  for any other  $x_i$ .

Oftentimes it is extremely difficult to quantify the elements of  $P_i$ . For example, suppose the elements of  $P_i$  include political stability, economic development, and attitudes toward the U.S. government. From a policy makers perspective, the temptation here is to take the element most easily quantified (in this case probably economic development) and attempt to maximize (minimize) it with the hope the others will follow along. Thus the motto "hard data drive out soft." Oftentimes, however, yielding to this temptation can have disastrous long-term consequences in the case where, over some interval, increases in economic development lead to a decrease in stability which in turn encourages hostility toward the U.S. A policy maker who simply optimized on economic development might soon be confronted with a rapidly deteriorating situation.

Once  $P_i$ ,  $C_i$ , and  $f(C_i, U)$  are developed, the problem becomes one of defining the objective function  $g(P_i)$ . In classical optimization problems,  $g(P_i)$  maps  $P_i$  (an  $m$ -element vector) into a single value (a scalar). In many economic applications, for example,  $g(P)$  is simply the sum of the dollar cost of the components of  $P_i$  and the goal is to minimize  $g(P)$  thereby minimizing total cost. However in many political applications there does not seem to exist a single dimension into which the elements



of  $P_1$  can be mapped. For example, there is no clear way to add dollars and political prestige. Therefore, instead of facing a scalar optimization problem, the political policy maker often faces what has been termed a vector maximization problem (Geoffrian, 1968). Satisfactory analytical solutions to most varieties of vector optimization problems are still non-existent.

Another aspect of the I.E. decision problem can best be viewed in terms of the concepts developed by Masarovic, Macko, and Takahara (1970). One of their concerns is with the designing of controllers for coupled subsystems. Coupled subsystems may be thought of as those in which changes in one subsystem may force changes in the other subsystem. The subsystems are in some way linked. If the O.E. of a government is seen as everything external to the government, then two subsystems of the O.E. might be the domestic subsystem and the international subsystem. Since changes in one can, under certain conditions, generate changes in the other, the two subsystems are coupled. A precise definition of coupling can be given in terms of properties of the matrices of coefficients of the subsystems, but in the context of this discussion, little if anything would be gained by such precision. Simon and Ando (1961) provide an interesting formal analysis of some aspects of coupling for those who would like a more rigorous approach.

Suppose, for illustration, that the O.E. is decomposed into an international and a domestic subsystem as in Figure 8.

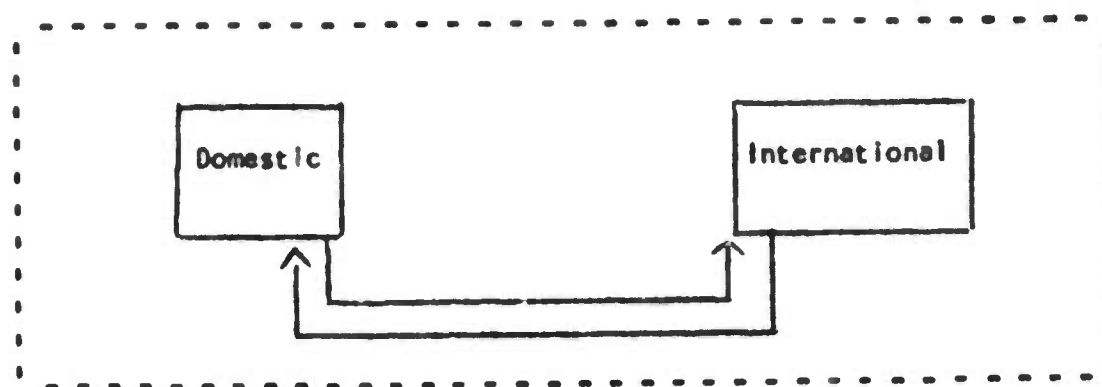


Figure 8

The O.E. is enclosed by dotted lines, and the lines connecting the two subsystems represent the coupling. In designing an i.E. structure to achieve goals in this O.E., it is likely that, since international problems are generally rather different than domestic ones, two "organizations" would be built into the i.E. These "organizations" might be the Ministry of Domestic Affairs and the Ministry of Foreign Affairs. Suppose further that the only way either Ministry can affect the subsystem it is concerned with is by spending political power units. Lastly, ignoring the interface problem by assuming there is no interface problem and that  $y$  is observed directly and accurately), results in what is pictured in Figure 9.

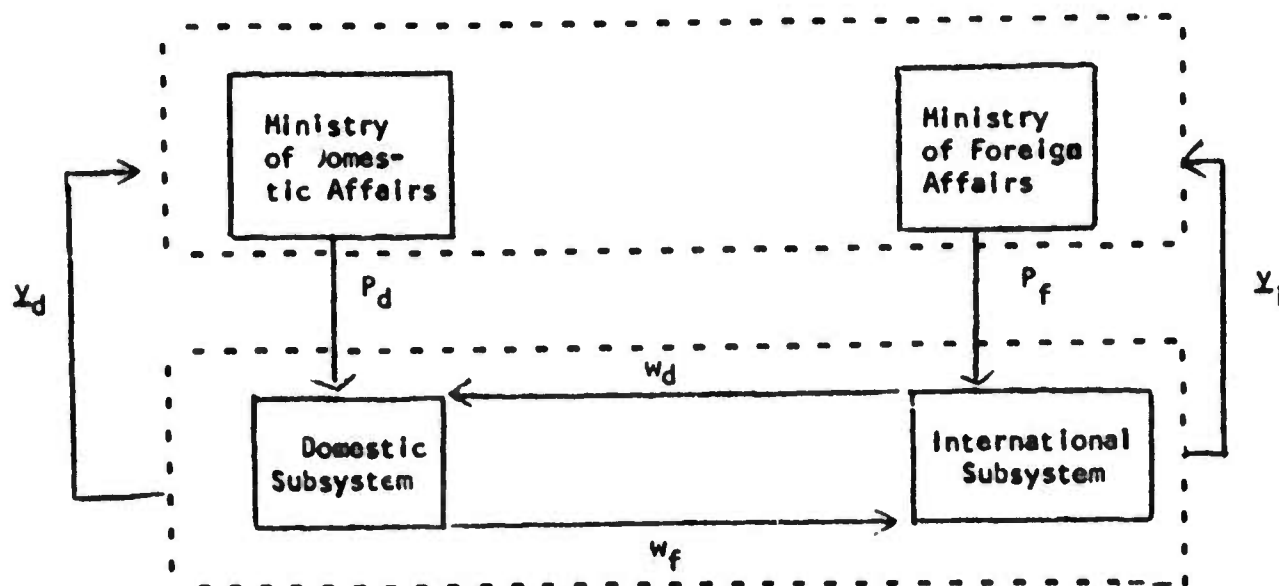


Figure 9



In the case of the Ministry of Domestic Affairs (MDA), power units ( $P_d$ ) expended in the domestic sub-system increase domestic satisfaction ( $S$ ) according to the equation:

$$(i) S = P_d - 2W_d.$$

The  $W_d$  in (i) is the interaction term representing the effect of changes in the international sub-system upon  $S$ . It will be specified further in equation (iii). The Ministry of Foreign Affairs (MFA) exchanges its power units ( $P_f$ ) for national defense ( $K$ ) according to the following:

$$(ii) K = 2P_f - W_f$$

Again,  $W_f$  represents how changes in the international sub-system affect the domestic sub-system. These interactions are:

$$(iii) W_d = S - 1/2P_s$$

$$(iv) W_f = K - 1/2P_f$$

Suppose the goal of the I.E. to move the O.E. to where  $K = 1$  and  $S = 1$ . If  $K$  or  $S$  is smaller than 1, it greatly increases the likelihood the government will fall out of power while values greater than 1 would signify a waste of power units. With this goal in mind, the sub-goals for the MDA and MFA would look as follows:

$$(v) \text{ MFA goal: minimize } (P_f^2 + 2(K-1)^2)$$

$$(vi) \text{ MDA goal: minimize } (P_d^2 + (S-1)^2)$$

And the overall I.E. goal then is to minimize the sum of the deviations from the sub-goals:

$$(vii) \text{ I.E. goal: minimize } (P_f^2 + P_d^2 + 2(K-1)^2 + (S-1)^2)$$

Suppose now the I.E.'s image of the O.E. ignores the coupling and assumes contrary to equations (i) and (ii) that the international and domestic processes are completely uncoupled, that is,

$$(i') S = P_d \text{ and,}$$

$$(ii') K = 2P_f$$

If the image is that described by (i') and (ii') above, then it can be shown that the values of  $P_d$  and  $P_f$  which best approach the sub-goal with a minimum expenditure are  $P_d = 1/2$  and  $P_f = 4/9$ . When put into equation (vii) (which may be thought of as an overall performance evaluation function), these values of  $P_d$  and  $P_f$  produce a value for (vii) of 4.09.

An important question then is, how much does ignoring the coupling cost the I.E.? It is at this point that the work of Masarovic, et al. becomes relevant. They demonstrate that by putting a controller over the MDA and the MFA as in Figure 8 and by taking into account the coupling this super-controller can, through proper coordination of the MDA and the MFA, increase the overall performance of the I.E. from 4.09 to .088 (where the lower the score the better the performance).

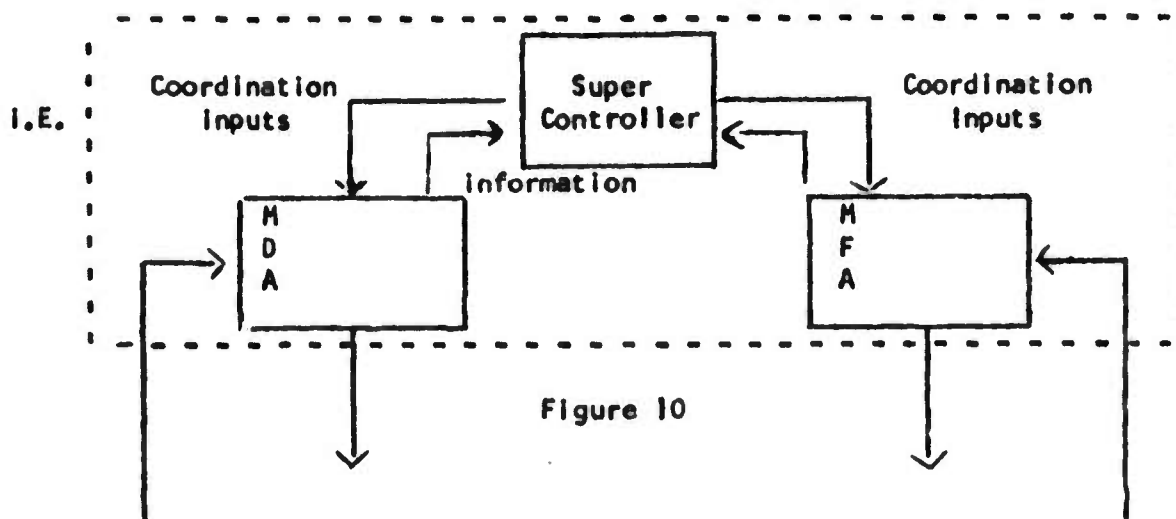


Figure 10

Depending upon the dimensions of the power, satisfaction, and defense units, the system cost of ignoring the coupling can be very high. Further examples of this type can be found in Mesarovic, et al. (1970) and Bailey and Holt (1971).

This illustration demonstrates once again how interdependent are goals, i.e. structures (including the image) and the O.E. Most all i.e.'s will have a structure similar to that of Figure 10, that is, the elements of the i.e. will be arranged hierarchically. Hierarchy here means "...a system that is composed of interrelated sub-systems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary sub-system." (Simon (1969), p. 87) Mesarovic, et al. (1970, p. 22) suggest some reasons why we find multi-goal systems so often arranged in a hierarchical fashion:

"...the overall goal of the organization which reflects the purpose of the organization as a whole is broken down into a sequence of sub-goals, so that the solution of the overall goal is replaced by the solution of the family of sub-goals."

However, as has been seen, specialization brings with it the problem of coordination. If each specialized unit is allowed to act independently and the various tasks are not completely uncoupled, resources will be used inefficiently and the nation will perform at a much lower level than it might otherwise. The first step in attempting to solve the coordination problem is to place more general units over the specialized units, thereby permitting the nation to operate as effectively as

possible. This is the procedure which was illustrated in the previous example. Figure 8 then represents a two-level, hierarchical structure. In this diagram the upward arrows refer to information and the downward arrows to coordination controls. The hierarchical, multilevel structure greatly reduces the amount of information which must be digested by any one group. As one moves up in level, the detail of information concerning each goal is reduced, thus allowing more goals to be considered at once. This increase in the number of goals presents significant problems to the decision makers attempting to implement them and to evaluate performance in achieving them. In order to discuss these difficulties, it is necessary to first be more explicit about some of the other elements in the problem structure.

The I.E. may be thought of as facing a decision as to what inputs ( $u$ 's) it ought to send into the O.E. to best move or retain the system in a desired state. The inputs are chosen by the I.E. on the basis of its image of the dynamics of the O.E. The decision problem is then defined by the goals, the interfaces, and the image. There are several ways the I.E. can modify its decision problem.

For example, it can change the image so that goals which previously looked unattainable now look attainable. Or, the I.E. can modify its goals in a way to make them attainable given the present image. It is in this way that goals can become changed or the structure of the I.E. can become modified. Third, it can construct new interfaces which allow the implementation of policies which previously were not

feasible. These first two techniques were to some extent treated in the previous paragraphs. To deal with the third (interface modification), the two interfaces must be examined in more detail.

This requires a look at how the government is able to put inputs into the O.E. and how it can monitor changes in the O.E.; that is the "hook-up" between the I.E. and the O.E. This "hook-up" has already been divided conceptually into two parts--the access interface and the observation interface. Both of these interfaces must generally be effective if the I.E. is to have a good chance of achieving its goals.

An important component of a nation's observation interface is some sort of social indicator system. Here "indicator system" is used in a very general sense to denote some set of O.E. elements whose values are measured at various points in time. GNP and unemployment rate might be two examples of economic indicators. Regime popularity and incidences of political violence might be several political indicators. The values of these interface measures are then evaluated by the I.E. in terms of its image of the O.E. and in part on the basis of this evaluation new policy outputs are generated.

The importance of an appropriate observation interface is again illustrated by the U.S. experience in Viet Nam. Following a crisis situation in Viet Nam (such as Tet), the U.S. response was to introduce some policy changes--generally in the form of increased military support to South Viet Nam. Ellsberg (1972) describes the characteristic Viet Minh and Viet Cong response to increased U.S. intervention:



"After suffering initial setbacks they would tie low for an extended period, gather data, analyze experience, develop, test, and adapt new strategies, then plan and prepare carefully before launching them (1972, 120)."

The U.S., however, monitored "enemy" strength through its field commanders who in turn equated frequency of enemy contact with enemy strength. If the enemy is strong, the reasoning went, then it will fight. If it is quiet, then it must be weak. Based on these reports, the tendency was always for the President to view his policy changes as a "success" which of course led to the periods of optimism and goal change discussed earlier. However, the U.S. observation interface was bad. Decreased contact did not mean a weakened enemy and, indeed, the periods of greatest crisis came at the times of highest U.S. optimism.

If policy outputs are to have any effect upon the O.E., the I.E. must have some way to get them into the O.E. This is done through the access interface. A task of the inner environment may often be the building of this interface prior to generating some other set of policy outputs. Thus a nation desiring to institute some land tax program based upon crop yield must first build an observation interface through which they can fairly accurately monitor crop production. It also must create some sort of access interface which will enable it to collect the taxes due it. Certain kinds of tax programs are often pursued in certain O.E.'s because, though they may have a slightly lower yield than other

feasible policies, of the ease of interfacing them with the O.E. An example in many U.S. states is the sales tax where the initial collection is made by already existing merchants and the amount collected is "naturally" controlled by sales volume.

Indeed, it may often be the only way for a government to achieve its goals is through the construction of new interfaces or the modification of old ones. The current controversy over wage-price controls in the United States may be seen as a debate on what access points the government requires in the O.E. if it is to achieve certain social and economic objectives.

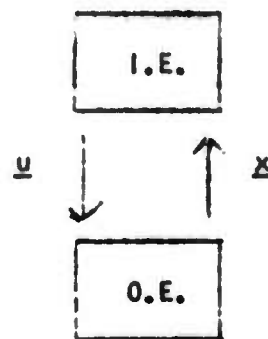
Thus far little attention has been paid to the international system--the O.E.--in which the national system--the I.E.--is attempting to achieve its goals. In light of last chapter's extended discussion of complexity, a first question might be, "Is it possible to construct an I.E. which is capable of adapting to any O.E. whatsoever?" Clearly if such universal adaptive structures can be shown to exist (in the mathematical sense of exist), then effort ought to be expended to translate a description of this structure into political terms.

More specifically, in political science terms, this question might be rephrased as "Is it possible to construct a government (I.E.) which is capable of adapting (maintaining state variables within specified limits) to any foreign or domestic environments (O.E.) it might be required to deal with?" Since such "universal governments" by definition can adapt to any O.E., the existence of such governments would greatly



reduce needs to acquire knowledge of specific O.E.s. However, the next Theorem (due to Gold (1965, 1971)) will show that such universal adaptors are impossible.

To make the problem simpler to conceptualize (but no less general), consider artificial systems whose access interface, observation interface and O.E. image are perfect. That is to say, that the I.E. can observe anything it chooses in the O.E. directly and without error, that it can put in "policies" exactly where, when and how it intends, and its image of the O.E. is (subject to certain constraints which will become clear) the O.E. itself. Thus the artificial system may be represented in its "reduced" structure as follows:



"Reduced" Artificial System Structure

Adaptation generally entails some sort of over time behavior and we can choose a time measure which is quantized (i.e. jumps from one unit to the next rather than being continuous) and has a finite starting point:

$$t = 1, 2, 3, 4, \dots$$

At each time point, the I.E. sends control outputs ( $u$ ) into the O.E.

These  $\underline{y}$  values can be thought of as being chosen from some finite alphabet  $U$ . Further, at each time point the O.E. receives inputs ( $\underline{x}$ ) from the O.E. The  $\underline{x}$  vector may be thought of as consisting of two components. The first,  $\underline{p}$ , are performance measures (e.g. level of satisfaction, etc.) and the second,  $\underline{i}$ , are (nonperformance) information about the O.E. The values of  $\underline{p}$  are expressed in a finite alphabet  $P$  and the values of  $\underline{i}$  in a finite alphabet  $I$ . (Those three alphabets need not be different, only distinguishable). Thus:

$$\begin{aligned}\underline{y}_t &\in U \\ \underline{p}_t &\in P \\ \underline{i}_t &\in I\end{aligned}$$

Again, without significant loss of generality, assume each of these alphabets to be coded as real numbers.

An inner environment can then be said to be adaptive if it is able to choose sequences of  $\underline{y}_t$  in such a way as to bring and maintain  $\underline{p}_t$  within specified limits. Note that the goal is simply to bring  $\underline{p}$  into some desired interval. The  $\underline{i}_t$  values simply give the I.E. information about the process but do not themselves enter directly into the I.E.'s objective(s).

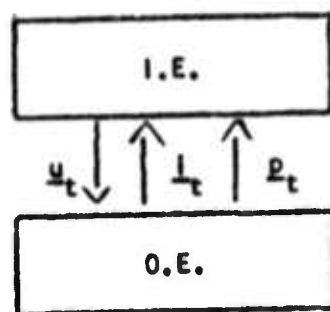
Still, however, the problem as posed does not have enough structure to be solved. More must be said about what kinds of O.E.s and I.E.s are being examined. A way of accomplishing this is to limit the class of possible I.E.s to those which have a finite number of states (that is, the I.E. at any point in time can only be in one of a finite number of states where state is used in precisely the same sense as earlier

and the class of O.E. to the class of finite automata (see Holt and Richardson (19\_\_)). The problem then becomes: "Is there a universal I.E. which will adapt to any (finite automaton) O.E.? Paraphrasing Gold (1971), it can be proven:

For any I.E. (finite state), there exists a finite state O.E. such that the I.E. will always behave in a strongly worst way.

In the argument which follows, an alphabet is defined as a non-empty set of real numbers and where  $A$  is the alphabet,  $A^*$  signifies the set of finite strings of elements in  $A$ . The three alphabets we will be referring to are  $U$  (policy outputs from the I.E.),  $P$  (performance inputs from the O.E.) and  $I$  (information inputs from the O.E.).

Thus:



The O.E. can be thought of as a function  $O_I$  from  $U^*$  to  $I$  together with a function  $O_P$  from  $U^*$  to  $P$ . In other words, the outputs of the I.E. ( $U^*$ ) determine  $I$  and  $P$  for the O.E. That is, we can say the I.E. and O.E. are linked. The I.E. then is a function  $E$  from  $(I \times P)^*$  to  $U$ . The outputs ( $U$ ) of the I.E. are determined by the pairs of  $I$  and  $P$  values generated by the O.E. (in response to previous  $u$ 's). More formally:

$$O_i: U^* \longrightarrow I$$

$$O_p: U^* \longrightarrow P$$

$$E: (I \times P)^* \longrightarrow U$$

These functions will result in the following sequences:

$$I_t = O_i(u_1, u_2, u_3, \dots, u_{t-1})$$

$$P_t = O_p(u_1, u_2, u_3, \dots, u_{t-1})$$

$$u_t = E(I_1, P_1; I_2, P_2; I_3, P_3; \dots, I_{t-1}, P_{t-1})$$

The sequence of I.E. outputs  $u_1, u_2, \dots$  is, as before, called the behavior of the I.E. With this vocabulary, strongly worst behavior can be defined. Suppose the set of P values is binary:

$$P = \{0, 1\}$$

$p = 0$  might be interpreted as undesirable and  $p = 1$  as desirable. A strongly worst behavior string,  $B^w$ , results if:

- 1) For the behavior string  $p_t = 0$  for all  $t$  but,
- 2) for any behavior string differing from  $B^w$  at any time,  $p_t = 1$  for all succeeding times regardless of future values of  $u_t$ .

In other words, a behavior is strongly worst if it results in the lowest possible value of  $p_t$  for all  $t$  and any other behavior would result in the highest possible value of  $p_t$  for all  $t$ . Certainly an I.E. which behaves in a strongly worst manner is not behaving adaptively no matter how wide a range is put on "acceptable limits." Thus if it can be proven that given any finite state I.E., a finite state O.E. can always be constructed toward which the I.E. will behave in a strongly worst manner, it will have been proven that there exists no universal I.E.

Suppose that the O.E. sends out a constant value of  $i$  for all  $t$ :

$$i_t = i \text{ for all } t$$

Thus the values of  $i$  are "independent" of the behavior of the I.E. When

$i_t = i$  and  $p_t = 0$  for all  $t$ , let the I.E. pass through States  $s_1, s_2, s_3, \dots$  producing outputs  $o_1, o_2, o_3, \dots$ . Since, by assumption, the I.E. has a finite number of states, it will finally have to repeat a state.

Let  $s_{n+1}$  be the first repeated state of the sequence  $s_{n+1} = s_m$ ,

where  $m \leq n$ . Then by assumption  $u_t$  must have the same period thereby

yielding  $o_{n+1} = o_m$ . Let the O.E. have  $n+1$  states  $S_0, S_1, \dots$

$S_n$  such that the O.E. is in  $S_0$ , it will send back  $p_t = i$ ; all other

O.E. states will send back  $p_t = 0$ . Let  $S_1$  be the initial (at  $t = 1$ )

state of the O.E. Finally then we can specify the state transformation

rules of the O.E. as follows: (where  $\longrightarrow$  may be read as 'moves to')

- (i)  $S_0 \longrightarrow S_0$  for all  $u_t$
  - (ii)  $S_j \longrightarrow S_{j+1}$  if  $u_t = o_t$
  - (iii)  $S_j \longrightarrow S_0$  if  $u_t \neq o_t$
- where  $j = 1, 2, \dots, n$  and  $S_{n+1} = S_m$

For example, if the O.E. is in State  $S_j$  and receives an input  $u_t \neq o_t$ , it will move to  $S_0$  and remain there for all future time regardless of future values of  $u_t$ . This yields a constructive proof that, if the O.E. is allowed to have as few as one more state than the I.E., an O.E. toward which the I.E. will behave in a strongly worst manner will always exist.

An example might make this more clear. Suppose  $n = 3$  (that is, the number of I.E. States equals 3). At  $t = 1$ :

<u>t</u>	<u>I.E.</u>	<u>O.E.</u>	<u>I</u>	<u>u</u>	<u>p</u>
1	$s_1$	$S_1$	1	$o_1$	0

Since the O.E. is not in  $S_0$ ,  $p_1 = 0$ . Further, since  $u_1 = o_1$  did not result in a desirable value of  $p_1$ , the I.E. will move to another state:

<u>t</u>	<u>I.E.</u>	<u>O.E.</u>	<u>I</u>	<u>u</u>	<u>p</u>
1	$s_1$	$S_1$	1	$o_1$	0
2	$s_2$	$S_2$	1	$o_2$	0

Again,  $u_2 = o_2$  produces an undesirable value of  $p_2$  and, because  $u_2 = o_2$ , the O.E. moved into State  $S_2$  as specified by transition rule (11). Time 3 yields the same results:

<u>t</u>	<u>I.E.</u>	<u>O.E.</u>	<u>I</u>	<u>u</u>	<u>p</u>
1	$s_1$	$S_1$	1	$o_1$	0
2	$s_2$	$S_2$	1	$o_2$	0
3	$s_3$	$S_3$	1	$o_3$	0

The I.E. has now exhausted its states. Suppose it moves back again to  $S_1$  (i.e.,  $m = 1$ ) thereby again going through the cycle. Here, then, is an example of how an O.E. with one more state than a given I.E. can always be constructed so that the I.E. will behave in a strongly worst manner.

This theorem proves that given an I.E., there will always exist an O.E. which is complex relative to that I.E. (complex in the sense of having more states) in which the I.E. will be unable to behave adaptively (no matter how weakly "adaptively" is defined). Additional theorems

have been proven (Gold, 1966, 1971) to demonstrate that even for teams of adaptors utilizing various strategies, there exist environments for which they will behave in a strongly worse manner.

The import of these results to political theory is not altogether clear. That there exist (in the mathematical sense) complex outer environment in which any given inner environment will behave in a strongly worst manner, is not, of course, to demonstrate that the particular outer environments in which national systems are located are of this type. It would seem plausible, however, at least that the outer environment of any national system has more system-states than does the national system itself. This is especially compelling if the national system is seen to be a part of its own O.E. At the very least, these results suggest that in designing governments, it is probably futile to attempt to construct a government which is capable of adapting to all O.E.'s. Instead careful study should be given to classifying the range of O.E.s. likely to be encountered by the government.



### Section V: Complexity and the International System

One way of classifying O.E.s might be in terms of their complexity relative to a given I.E. As was argued elsewhere (Thorson, 1972) the notion of complexity involves enormous analytic, conceptual and empirical problems. However, regardless of these difficulties, complexity has the advantage of being in part contingent upon national system structure and of fitting in nicely with some aspects of organization theory. The utility of these characteristics should become more apparent in the ensuing discussion.

While it seemed to make intuitive sense to argue that some systems (e.g., O.E.s) are inherently more complex than others, such a "non-contingent" view of complexity often leads to more problems than it resolves. What seems to be true is that no satisfactory definition of the complexity of an environment can be given independent of the class of systems "operating" in that environment. The reason for this is that the system can be so designed as to remove some of the "intuitive complexity" from the environment. For example, many living species may well be facing a less complex environment now than they did thousands of years ago. Through evolution many of the common relational structures have been "pre-programmed" into the human brain. The brain has developed in such a way as to operate extremely effectively in an environment of three dimensions, fast response times (the time it takes for the environment to respond to external stimuli), and few relevant variables. This pre-programming of complexity through evolution

or design may well be a key to any system's operating adaptively in a seemingly complex environment.

What of the international political system (a foreign policy maker's O.E.)? It is doubtful that the international political system is of the three dimensional, fast response time, and few relevant variable type. Indeed, the "high order, multiple loop, non-linear feedback structure" discussed by Forrester (1969) would seem to be far more descriptive of the international system:

It has become clear that complex systems are counter-intuitive. That is, they give indications that suggest corrective action which will often be ineffective or even adverse in its results. Very often one finds that the policies that have been adopted for correcting a difficulty are actually intensifying it rather than producing a solution.

Choosing an ineffective or detrimental policy for coping with a complex system is not a matter of random choice. The intuitive processes will select the wrong solution much more often than not. A complex system--a class to which a corporation, a city, an economy, or government belong--behaves in many ways quite the opposite of the simple systems from which we have gained our experience.

Most of our intuitive responses have been developed in the context of what are technically called first-order negative-feedback loops. Such a simple loop is goal-seeking and has only one important state variable. For example, warming one's hands beside a stove can be approximated as a first-order, negative-feedback loop in which the purpose of the process is to obtain warmth without burning one's hands. The principal state variable of the loop is the distance from the stove. If one is too close he burns his hand, if too far away he receives little heat. The intuitive lesson is that cause and effect are closely related in time and space. Temperature depends on the distance from the stove. Too much or too little heat is clearly related to the

position of the hands. The relation of cause and effect is immediate and clear. Similarly, the simple feedback loops that govern walking, driving a car, or picking things up all train us to find cause and effect occurring at approximately the same moment and location.

But in complex systems cause and effect are often not closely related in either time or space. The structure of a complex system is not a simple feedback loop where one system state dominates the behavior. The complex system is of high order, meaning that there are many system states (or levels). It usually combines positive-feedback loops describing growth processes as well as negative, goal-seeking loops. In the complex system the cause of a difficulty may lie far back in time from the symptoms, or in a completely different and remote part of the system. In fact, causes are usually found, not in prior events, but in the structure and policies of the system.

To make matters still worse, the complex system is even more deceptive than merely hiding causes. In the complex system, when we look for a cause near in time and space to a symptom, we usually find what appears to be a plausible cause. But it is usually not the cause. The complex system presents apparent causes that are in fact coincident symptoms. The high degree of time correlation between variables in complex systems can lead us to make cause-and-effect associations between variables that are simply moving together as part of the total dynamic behavior of the system. Conditioned by our training in simple systems, we apply the same intuition to complex systems and are led into error. As a result, we treat symptoms, not causes. The outcome lies between ineffective and detrimental.

Actions directed at individual nations often have indirect and unforeseen consequences. Sometimes these consequences take years and even decades to make themselves known. Solutions to specific problems often result in making things worse rather than better. In short, nations' foreign policy responses often have not been well selected. This poor selection may stem partly from man's proclivity to look in the international environment for kinds of relational structures of encounters in his day to day experience.

The complexity of the international environment is in part dependent upon the structure and goals of the national system which is attempting to deal with it. Thus different national systems may view a given international environment as more or less complex. It is, however, possible to identify some characteristics to look for in environments:

- (1) The number of relevant variables. In general, the greater the number of relevant variables, the more complex the environment.
- (2) The response time of the environment. In general, the longer it takes for an environment to respond to foreign policy inputs, the more complex it is.
- (3) Amount of randomness in the environment. Here the concern is with how much variance is associated with the response of the international environment to a given foreign policy input from a given national system. The greater the variance, the greater the randomness. In general, the greater the randomness, the more complex the international environment.

With relatively few additional assumptions, these notions can be used to derive a number of qualitative propositions relating the complexity of the international system (O.E.) to the foreign policy responses of an adaptive national system (I.E.). While the deviation of these propositions is outside the scope of this chapter, one such proposition will be derived as an example of the procedure which might be employed.

It has been assumed that a national system generates foreign policy outputs in a way designed to achieve certain goals. These goals may be thought of as desired system states. It was noted that outputs

of adaptive systems are chosen as a result of a historical record together with the present system state. It was also stated that adaptive systems may at times make the "wrong" choice. By a wrong choice it is meant that the system could have chosen a different output which would have resulted in the system's moving to a more desired state. Through the feedback process the system can generally assess the effect of its output and correct certain kinds of errors.

In this discussion it will be assumed that some sort of learning mechanism is present in the national system. This learning mechanism will be a member of the class of familiar trial and error types. Each time the system has to generate a foreign policy output, a number (this number may be one) of alternatives are considered. Each of these alternatives has associated with it some probability of being chosen as the foreign policy. After an output is chosen, its effect is evaluated by some decision component according to some rule. After this evaluation, the alternatives are assigned new probabilities of being chosen. This sort of decision procedure will generally yield a negatively accelerating learning curve as in Figure 11.

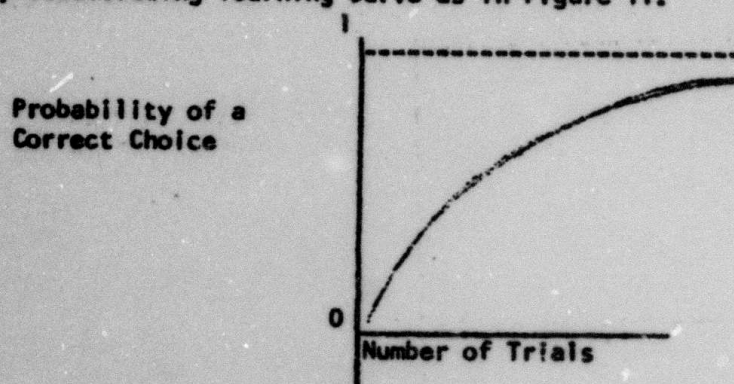


Figure 11



By a correct foreign policy it is meant a foreign policy output which will result in meeting some well-defined goal, i.e., an adaptive behavior. In some cases there may be more than one correct choice. The curve of Figure 11 will still hold. What Figure 11 is saying is that, in general, the probability of a correct choice increases with the number of trials.

More specifically, it will be assumed that the particular learning mechanism will be one similar to that described by Norman (1964) and that the foreign policy responses generated by the I.E. are made on the basis of information gained from previous responses in situations deemed similar. It is further assumed that there exists an optimal policy (in the sense defined earlier), and it is the task of the I.E. to identify and implement this policy. (This formulation ignores Simon's (1957) claim that large scale organizations will often exhibit "satisficing" rather than optimizing behavior)!

The probability of the I.E. choosing a sub-optimal policy will be some number "q" where  $0 \leq q \leq 1$ . In describing foreign policy behavior, the task then becomes to relate the value of "q" on one trial to that of "q" on another. A trial is simply a perception on the part of the I.E. of a decision problem together with the I.E. policy response to that decision problem. In psychological terms, the perception of a decision problem corresponds to the stimulus and the chosen policy as the response.

In a theory of I.E. policy selection, all those trials in which the relevant component of the I.E. perceives the decision problem in a

similar way can be treated as an equivalence class of events (trials). It is responses to trials which belong to the same equivalence class that the theory will attempt to describe. Again, in the vocabulary of learning theory all trials which have "similar" stimuli will be considered to be in the same equivalence class independent of the I.E.'s selected policy response.

With the help of the preceding vocabulary, the specific learning mechanism being posited can be described more rigorously. On each trial "n", the I.E. will respond with a sub-optimal policy with a probability " $q_n$ " and with an optimal policy with a probability " $p_n$ " where, of course:

$$(6) \quad p_n = 1 - q_n$$

On any given trial, the I.E. may or may not learn from its response how to better respond on the next trial. This will be represented by a random variable " $y_n$ " which will equal one if learning took place on trial "n" and zero if no learning took place. Further, the probability that learning takes place on any trial will be represented by "c."

Thus:

$$(7) \quad y_n = \begin{cases} 1, & \text{with probability } c \\ 0, & \text{with probability } 1-c \\ \text{where } 0 \leq c \leq 1 \end{cases}$$

The main axiom describing this learning mechanism describes the relation between the probability of selecting a sub-optimal policy on one trial and that of selecting a sub-optimal policy on the succeeding trial.

It can be stated in a single difference equation:



Error Curve When:  $\alpha = .6$      $c = 1.0$      $q_1 = 1.0$

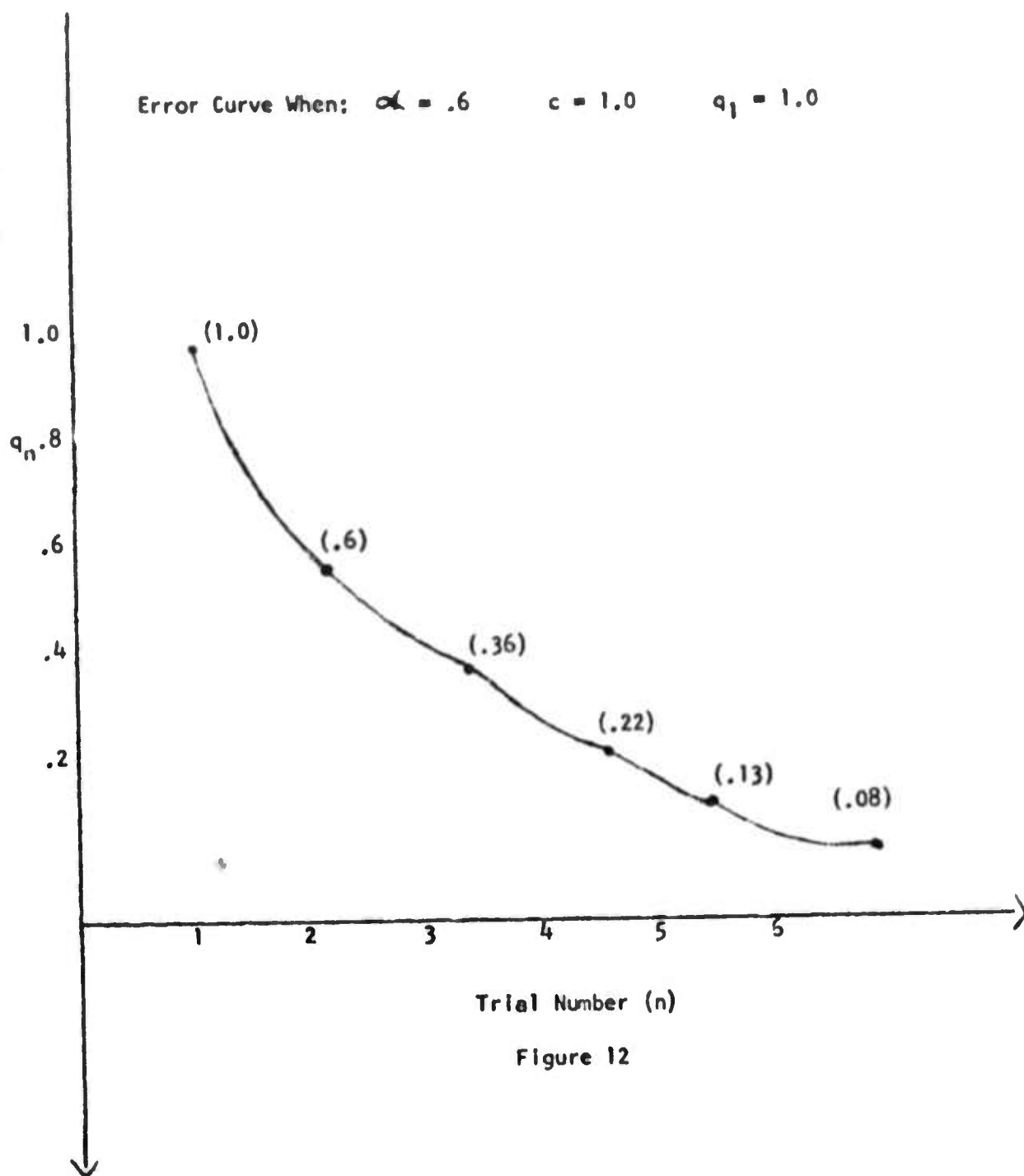


Figure 12

64-A

$$(8) \quad q_{n+1} = \alpha y_n + (1-\alpha) q_n$$

Since " $y_n$ " will equal either zero or one, the above difference equation can be split into two equations:

$$(9) \quad q_{n+1} = \begin{cases} \alpha q_n, & \text{with probability } c \\ q_n, & \text{with probability } 1-c \end{cases}$$

Equation (8) [or, equivalently, equation (9)] simply provides a rule by which the result of one trial affects the probability of selecting a sub-optimal policy on the next. More specifically, it states that each successive "increment of learning" is smaller than the previous one (unless  $c=1$  and  $\alpha = 0$ ) in which case "all or none" learning takes place and the probability of selecting a sub-optimal policy goes to zero as soon as any learning takes place.

The behavior described by (8) is illustrated in Figure 12. Here " $q_1$ " (the probability of selecting a sub-optimal policy on the first trial) is 1.0, " $\alpha$ " is 0.6 and " $c$ " is 1.0. Notice the downward sloping (at a decreasing rate) error curve approaching " $q_n$ " equal to zero as an asymptote. It can be seen in equation (8) that, all other things being equal, the smaller the value of " $\alpha$ ", the faster the rate of learning (i.e., the faster the value of " $q$ " decreases).

More importantly, an inspection of (8) reveals that the equation has two parameters, " $c$ " and " $\alpha$ ". This fact can be used to solve (8) for various statistics in terms of " $\alpha$ " and " $c$ ". For our purposes two of the most important statistics are the expected number of sub-optimal

responses in an infinite number of trials  $E(T)$  and the variance about the expected total number of sub-optimal responses  $\text{var}(T)$ . Equations in terms of "c", "r" and "q" for these two statistics can be derived from (8) above (for the derivations of these as well as other statistics see Norman (1964) to yield:

$$(10) \quad E(T) = \frac{q_1}{c(1-q_1)} \left[ 1 + \frac{2}{q_1} \left( \frac{q_1^2 + (c+1-c)}{c(1-2q_1)} \right) - E(T) \right]$$

$$(11) \quad \text{var}(T) = E(T) \left[ 1 + \frac{2}{q_1} \left( \frac{q_1^2 + (c+1-c)}{c(1-2q_1)} \right) - E(T) \right]$$

If there is no additional information, "q" is generally thought to equal  $(1 - \frac{1}{r})$  where "r" is the number of alternative policies and (since the I.E. has no additional information) the I.E. must simply select one "at random." From (10) it is clear that (all other things being equal) as "q" gets larger,  $E(T)$  gets larger. That is, under the posited learning mechanism the larger the initial probability of selecting a sub-optimal policy, the greater will be the expected total number of sub-optimal policies which will be selected.

Based upon the previous discussion, it can be said that with respect to a fixed I.E., and a given decision problem, O.E. becomes more complex as it becomes more "difficult" for the I.E. to respond with an optimal policy. Moreover, the learning mechanism described above permits an unambiguous (though not necessarily unobjectionable) index of the difficulty of a decision problem -- the greater the value of  $E(T)$  for a given decision problem the greater the difficulty of that decision problem. As has been seen,  $E(T)$  is dependent upon "q", "c" and "r" and will increase with decreases in "q" or "c" or increases in "r".

In most instances the values " $q_1$ " and " $\alpha$ " (the learning rate parameter) would seem to be dependent upon the structuring of the I.E. This may not be the case with " $c$ ." In terms of the theorem proved earlier concerning the impossibility of a universal adaptor, " $c$ " reflects the probability that performance information in  $p_t$  will be used in such a way as to decrement the value of  $q_t$  on the next trial (it would be interesting to change the learning mechanism to allow information to be utilized in such a way as to actually increment the value of  $q_t$  [as in some kinds of hypothesis learning]). As the value of " $c$ " decreases, both  $E(T)$  and  $\text{var}(T)$  increase dramatically as can be seen in Table 4.

Table 4

Values of  $E(T)$  and  $\text{var}(T)$  for selected values of " $c$ "  
 $[q_1 = .667, \alpha = .5]$

	$E(T)$	$\text{var}(T)$
$c = 1.0$	1.33	0.74
$c = 0.5$	2.0	3.34
$c = 0.1$	13.34	45.49

The parameter " $c$ " might be interpreted as being the probability that the O.E. will send a "usable" (i.e., one that enables learning to take place) performance response to the I.E. The greater the value of " $c$ " the fewer the expected total number of sub-optimal policy outputs and the smaller will be the variance about this expectation. In general, it would be thought that sub-optimal policies would (assuming an effective access and observation interface) be followed by an O.E. response indicating "low" performance and the value of " $c$ " would be very high.

However, if there is considerable randomness in the O.E. this need not be the case as the performance response of the O.E. to equivalent policy inputs would not be deterministic, but rather would be governed by some probability function. The probability that effective learning would take place on any given trial ( $c$ ) would generally decrease as the randomness in the O.E. increases.

It seems plausible to argue that as the randomness of the O.E. increases its complexity will either remain the same (if the increased randomness does not affect the particular decision problem being studied) or increase (if the increased randomness does affect the decision problem). In the rest of this paper "increased randomness" will refer only to the later case where the particular decision problem of interest is affected. With this restriction on the use of "increased randomness," it seems that increases in the randomness will increase the complexity of the O.E. by decreasing the value of " $c$ ."

If this be so, a proposition relating changes in the complexity of the O.E. to the variance  $\{var(T)\}$  of the O.E.'s foreign policy behavior immediately follows (it will be assumed that the interfaces are constant and effective enough to handle the outputs generated and to adequately observe their effects.)

Proposition: The more randomness in the international environment, (O.E.) the greater will be the overtime variance  $\{var(T)\}$  in a national system's foreign policy outputs.

This proposition asserts that when a given policy output does not have the same effect upon the environment, the national system moves from policy to policy in an attempt to find a correct one. Supposing there is a correct response, the randomness in the environment may, at times, have the effect of making a "correct" choice appear incorrect. Thus it will take more trials to learn the correct response and there will be considerable movement about the set of possible responses. The result of this will be to make the national system operating in such an environment appear to have a vacillating or inconsistent foreign policy. An example of this might be U.S. foreign aid policy since World War II. Here the U.S. appears unable to decide whether foreign aid should take the form of large amounts of dollars or technical assistance. One could argue that this vacillation is the result of not getting similar environmental responses from policy outputs which were thought to be the same. Thus the U.S. cannot decide between big money and technical assistance.

The derivation of this proposition under the particular learning mechanism being posited should be clear from the earlier discussion. Increasing the randomness in the O.E. results in decreasing "c" and as "c" decreases,  $\text{var}(T)$  increases (see Table 4 for a numerical example).

While there are a number of other propositions which could be made relating the complexity of the environment to national foreign policy behavior, it is important to mention some possible effects of the interface on foreign policy outputs.



So far, it has been assumed that the interfaces were constant and effective. In many cases this assumption is not valid. There are times when the national system simply cannot access the environment in the way that it wants. As a result, it cannot achieve certain of its desired states. Even more often there are problems with the observation interface. Either the national system does not know that variables to look at to assess its policy or the variables are not directly observable and measures for them are unreliable. Some of the controversy over arms limitations may be seen as stemming from difficulty in the observation interface. Here the stakes are very high, and the national system is not certain it can measure accurately the effect of an arms limitation policy. In such a circumstance it is highly unlikely that a limitation policy will be put into effect. The reason for its not being adopted may be due not to uncertainty in the environment but rather to being unable to adequately observe the state of the environment. Generally when it is thought an output choice could possibly result in moving the national system to a highly undesirable state if it is not corrected quickly and if its effect is not observable, then the output will probably not be generated even though it is highly probable that the outcome will be very favorable to the national system. This proposition in effect says that the adaptive national system will not attempt to optimize on a particular objective if it realizes that it could be badly hurt if the environment does not respond to its policy the way it forecasts it will and the national system cannot observe quickly enough what the environmental response is.



In view of these few propositions, certain foreign policy strategies become apparent. For example, if the environment is fairly random, a nation wanting to meet some goal might first try to structure the environment to make it more predictable. This notion is implicit in British foreign policy in the 19th century. Further, Alger (1961) has speculated that one of the effects of the United Nations is to make the world more predictable. This in turn means national policies can be more consistent.

Conversely, a national system which was a part of another national system's international environment might want to make its responses somewhat random to force the second nation into adopting an inconsistent policy toward it. Thus, for certain purposes a nation might want to increase the randomness in the international system.

Certainly none of the propositions which have been made are "new" to the study of foreign policy. They can be found, in various forms, throughout the literature. However, that they follow from the framework developed in this paper is of some interest. For this framework gives a language and a structure with which we can relate the national system to its international environment. Relatively few propositions have been presented of the many that could have been. The purpose, however, of this paper has not been to introduce propositions, but to sketch a unified perspective from which to begin to theorize about a "complex" social phenomenon--national foreign policy behavior.

Summary

If foreign policy behaviors are to be viewed as being generated by adaptive national systems, then a language appropriate to this focus must be introduced. The concepts surrounding Simon's notion of an "artificial" system provide one such vocabulary. Artificial systems may be thought of as a subset of general systems and are characterized by such concepts as "goals", "inner environments", "outer environments", and "interfaces." An adaptive national system was then defined as a government (I.E.) attempting to achieve goals (maintain state variables within specified limits) in an O.E. consisting of (at one level of disaggregation) the domestic environment and the interactional system. Several additional components of adaptive systems were mentioned and some of their implications for national systems were discussed. The definition of an adaptive system was employed to prove the impossibility of a universal adaptor and this result was used to suggest that O.E.'s be classified as to their complexity with respect to a given I.E. (national system). An illustrative proposition was derived utilizing this approach.

## References

- Ackoff, R. Scientific Methods: Optimizing Applied Research Decisions. Wiley: New York, 1962.
- C. Alger (1961), "Non Resolution Consequences of the United Nations and Their Effect on International Conflict," In Journal of Conflict Resolution, Vol. V, No. 2 (June, 1961), pp. 128-145.
- Ando, A., F.M. Fisher, H.A. Simon (eds.), Essays on the Structure of Social Science Models (Cambridge, Mass.: M.I.T. Press, 1963).
- Arbib, M.A., "Automata Theory and Control Theory--A Rapprochement," Automatica, III, pp. 161-189.
- Arbib, M.A., Theories of Abstract Automata (Englewood Cliffs, N.J.: Prentice Hall, 1969).
- AsiBy, M.B. (1952), Design for a Brain, Butler and Tanner Ltd., (Fromme and London).
- Ashby, W., "What is an Intelligent Machine?," in Ludwig Von Von Bertalanffy and Anatol Rapoport (eds.), General Systems Yearbook, Vol. VIII, 1963.
- Bailey, F. and R. Holt, "Towards a Science of Complex Systems," mimeo, 1971.
- Barnett, Lincoln, The Universe and Dr. Einstein (New York: Harper and Brothers, 1948).
- Blum, M., "A Machine-Independent Theory of the Complexity of Recursive Functions," J.A.C.M., XIV, pp. 332-336.
- Bobrow, "International Indicators," paper prepared for delivery at the 1969 Annual Meeting of the American Political Science Association, Commodore Hotel, New York City, 2-6 September 1969.
- Botvinnik, M., Computers, Chess and Long-Range Planning (Springer-Verlag, 1970).
- Brandl, John, "Constrained Maximization and Decision Rules in Government: An Analysis of an Investment Allocation Formula," mimeo, undated.
- Brunner R., and Brewer, G. Organized Complexity. New York: Free Press, 1971.

- Brunner, Ronald, "Data Analysis, Process Analysis, and System Change," paper prepared for delivery at the 1970 Annual Meeting of the American Political Science Association.
- Cain, G. and H. Watta, "Problems In Making Policy Inference from the Coleman Report," American Sociological Review, (April, 1970). pp. 228-252.
- Carr, E.H. (1944), Conditions of Peace, The MacMillan Company, (New York).
- Coghill, G., Anatomy and the Problem of Behavior, C.U.P., 1929.
- Coombs, C., R. Dewes, and A. Tversky, Mathematical Psychology (Englewood Cliffs, N.J.: Prentice Hall, Inc., 1970).
- Ellsberg, D. Papers on the War. Simon and Schuster: New York, 1972.
- Fogel, L., A. Owens, and M. Walsh, Artificial Intelligence through Simulated Evolution (New York: John Wiley & Sons, Inc., 1967).
- Formby, J., An Introduction to the Mathematical Formulation of Self-Organizing Systems (E. & F.N. Spon, 1965).
- Forrester, J., Urban Dynamics (Cambridge, Mass.: M.I.T. Press, 1969).
- Forrester, J. Industrial Dynamics. M.I.T., Cambridge, 1961.
- Geoffrion, A. Proper Efficiency and the Theory of Vector Maximization. Journal of Mathematical Analysis and Applications, 1968, 22(3), 618-630.
- Gold, E. Universal Goal Seekers. Information and Control, 1971, 18, 395-403.
- Gold, E. Models of Goal-Seeking and Learning. (Doctoral dissertation, UCLA) Ann Arbor, Mich.: University Microfilms, Inc., 1965.
- Gregory, R., "On How so Little Information Controls so Much Behavior," In Toward a Theoretical Biology 2 (Edinburgh University Press, 1969).
- Gunn, J. The Problem of Time. Allen and Unwin, 1929.
- Harrieder, W. (1967), "Computability and Consensus: A Proposal for the Conceptual Linkage of External and Internal Dimensions of Foreign Policy," American Political Science Review, LXI (December, 1967), pp. 971-982.
- Holt, R. and J.M. Richardson, Jr., "Applications of Automata Theory to the Explanation of Political Development," paper prepared for delivery at the 1969 Annual Meeting of the American Political Science Association.

- Hull, C. Principles of Behavior. New York: Appleton, 1943.
- Kanter and Thorson, The Logic of U.S. Weapons Procurement. in Rosen, ed. Testing the Theory of the Military Industrial Complex (in press).
- Kemeny, J., A Philosopher Looks at Science. (Princeton, N.J.: D. Van Nostrand, 1959).
- Kulikowski, R., "Control and Organizational Structure in Large Scale Systems," Space Science Center, University of Minnesota, 1970.
- Levins, R., "Complex Systems," in Toward a Theoretical Biology 3 (Edinburgh University Press, 1970).
- McGowan, P. (1970), "A Formal Theory of Foreign Policy as Adaptive Behavior," Paper delivered to the 66th Annual Meeting of the American Political Science Association.
- Mesarovic, M., D. Macko, and Y. Takahara, Theory of Hierarchical Multilevel Systems (New York: Academic Press, 1970).
- Minsky, M., Computation Finite and Infinite Machines (Englewood Cliffs, N.J.: Prentice Hall, 1967).
- Morgenthau, M. (1961), Politics Among Nations, 3rd Edition, Alfred A. Knopf, (New York).
- Murphy, R.E., Jr. (1965), Adaptive Processes in Economic Systems, Academic Press, (New York).
- Norman, M., "Incremental Learning on Random Trials." J. Math Psychology 1, 336-350, 1964.
- Ornstein, R. On the Experience of Time. Middlesex: Penguin, 1969.
- Richardson, J. and Pelsoci, T., "Measuring Satisfaction in Urban Systems." A preliminary report of the Urban Organizational Design and Control Project, Case Western Reserve University, mimeo, 1971.
- Richardson, J. (1969), Partners in Development, Michigan State University Press, (East Lansing).
- Rosenau, J. (1970), The Adaptation of National Societies: A Theory of Political System Behavior and Transformation, McCaleb-Seiler, (New York).
- Rosenau, J. (1967), "Competability, Consensus, and an Emerging Political Science of Adaptation," American Political Science Review, LXI, (December, 1967), pp. 983-988.



- Samuelson, P. "Interactions Between the Multiplier Analysis and the Principle of Acceleration." Review of Economic Statistics, XXI, May, 75-78, 1939.
- Shannon, C., "Programming a Computer for Playing Chess," Philosophical Magazine Vol. 41 (March, 1950).
- Shaw, R., "Cognition, Simulation, and the Problem of Complexity," mimeo, 1970.
- Shaw, R. and J. Jenkins, "Gedanken Experiments for Organisms too Complex to be Modelled," mimeo, 1970.
- Simon, H., The Sciences of the Artificial (Cambridge, Mass.: M.I.T. Press, 1969).
- Simon, H., Models of Man (New York: Wiley, 1957).
- Tarski, A. Introduction to Logic, 3rd ed. Galaxy, 1966.
- Thom, R., "Topological Models in Biology," in C.H. Waddington (ed.), Towards a Theoretical Biology 3 (Chicago: Adline Publishing Company, 1970).
- Thom, R., "Une theorie dynamique de la morphogenese," in C.H. Waddington (ed.), Towards a Theoretical Biology 1 (Chicago: Aldine Publishing Company, 1968).
- Thorson, S. "The Role of Mathematics in Political Theory Construction" (Doctoral Dissertation, University of Minnesota, 1972).
- Thorson, S. "Modelling Social Processes as Dynamic Systems." Paper presented at the 1971 Annual Meeting of the American Political Science Association.
- Toda, M. and E. Shuford, "The Logic of Systems: An introduction to a Formal Theory of Structure," in Ludwig Von Bertalanffy and Anatol Rapoport (eds.), General Systems Yearbook, Vol. X (1965).
- Von Neuman, J., "Rigorous Theories of Control and Information," in Theory of Self-Reproducing Automata (University of Illinois Press, 1966).
- Waddington, C.H., Strategy of the Genes (London: Allen and Unwin 1957).